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SOILS, CROPS, AND MEN: A STUDY IN HARMON

M. L. WILSON[2]

I AM supposed to talk to you this forenoon about soils, crops, men. Now I am heartily in favor of all three of these things, so subject suits me very well. I am especially glad that word included. If I had to deal only with soils and crops, I might to get up here before an audience of scientists speciali two things. They might hand me a generous gift of one the raspberry. The Greeks might be translated brin the fruit doesn't so y it clusion of this word can co human aspects of th

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One more point, h topic, soil men, is really a vast one. If I tried to cover it adequately certainly overstretch my mind—and you know what you put too much gas into a balloon. It bursts, and that I don't want you to have to witness the painful spectacle of the of the Undersecretary of Agriculture suddenly scattering in all tions at once preliminary to complete disappearance, so I shall co myself to certain aspects of this subject.

What aspects shall I cover? Well, some of you who know sonally know that one of my enthusiasms—an inordinate e if you want to call it that—has to do with all those aspect that make farming a way of life as well as a means of li lieve that the best home is a home country life. And believing that, in the possibilities of the fam

poor men that guns and national glory are of greater satisfying the need of their bodies for vitamins? No and because it would take too long to argue the shall accept this dream of material abundance a incidentally that even before there was any s created in man's thoughts was in some form a la. and honey. Common men, it would seem, have for felt that spiritual values can best be considered including a little dessert

Well, what has happened to this latter-day d based on the promises of science? Somehow ou achievement is not so bright as it used to be In fa almost any noble aim you could mention is not time when men are very unsure of themselves, w ally unsure of the reality of anything good; in fac more likely to be sure of the reality of things e large, they have seen that which is evil come to pa the future with foreboding A shadow passes betw and like the men of old we dread the eclipse and tion of things we hold dear

Yet the achievements of science and technology solid ground. You in this audience, you who deal plants, know better than anyone else that they hold what has already been done, and you can confidently further achievements in the future You know that dream of abundance, the production half, is already the Shall we, then, because we live in a time of wides skep and pessimism—shall we give over the other half o eam we say, Yes, we can produce, but it is beyond et wh produce into the hands of those who need it? Sha within sight of a land of milk and honey, if I may u in a free sense, and then just squat on our haunch on outskirts?

No, this is not a time to give up. And I do not th is a time retreat to the way of life of a former day It is a tim efforts because the goal unquestionably is so much n If frozen and cumbersome economic institutions sta achievement, then it is time to begin thawing out th and remaking them to suit the needs of a science and abundance. In the United States, more than in any o the world, there should be hope of doing this Leas Americans think of retreating. In this country scie ee, resources are the greatest, institutions are, or be ost flexible and responsive to human needs; and ere is the least need or excuse for those fantastic of est and those costly adventures in imperialism tha he od of nations, brutalize whole peoples, and condemn ch lock-step in the chain-gang of militarism.

only do we in the United States have a bett toward a real

echnology can create when it works upon excellent
lso an urgent and primary need as a means of defense
external and internal, that do not bode well for this
earer we come to realizing the dream of a good life for
ens—or to put it another way, the better adjusted all
r environment—the more each of us will have to defend,
united we shall be in defending it against any threat of
xternal or internal

t such an achievement would make us soft. The path
easy one; in fact, the danger is that we will attempt
th, and fail. As you men of science know, creating rela-
abundance for everyone will involve hard work, self-
nd a high degree of cooperation These are not the things
men or nations soft. They are more likely to become soft
ljustments between man and his environment are allowed
course, so that misery deepens, morale is shattered, hope-
s in, and nothing vigorous is done to stop these things; or
vileged class is permitted to live luxuriously on the fruits
e and conquest.

ave said this much to make it clear that I believe we must
very promising line of attack and every promising experi-
seek new ones, to bridge the disastrous gap between the
es of production and the actualities of distribution. And
s light that I would have you regard my own personal in-
n a greater development of self-sufficient farming. It is all part
arcel of the same problem. And I do not regard greater self-
ency on the part of farmers as the whole answer to the problem.
would be a narrow-minded and fanatical and unrealistic view.
self-sufficiency in farming may be only a very small part of the
But wherever we can find a part of the answer, that is all to
good, it is that much gained

ow I want to say that you soils men are responsible for making
ven a little more set in some of my beliefs than I was before The
rtment of Agriculture recently got out a big book called *Soils
Men*, the 1938 Yearbook of Agriculture Some of you cooperated
e making of that book. Now what do I find when I look into this
volume? I find that over and over again, one theme is stressed—
relationship of the man to the soil The emphasis is not on man
ly as a cultivator who does or does not fertilize the soil properly,
l terraces correctly, or do this or that—but on man as a com-
being, making a home, raising a family, paying taxes, and man as
tegral part of a broader social group.

e writ[illegible] that we have had serious erosion and soil depletion
r country already, new as it is. They explain vividly what has
ened, what is happening, and above all, what we may expect in
uture if, as a whole people, we disregard the [illegible]
upset [illegible] balance. Why are they so concerned [illegible]
ediate [illegible] to our food supply? Although [illegible]
be pl[illegible] in [illegible], this does not get [illegible]
[illegible]

suitable for farming with any known system of man . at under the current or expected price levels? What of those on 8 million acres that have low yields, soil erosion, or both, but . could be managed safely with methods already demonstrated t · practical? What of these people and their children?

That some of these people are allowing erosion to take place is likely their own fault, perhaps heedlessness or ignorance of what is happening. But more often, it is explained, individuals, acting alone, are helpless to do the things that should be done. Your indictment is against society, the group, rather than against the individual. Yet you say that some soils have been improved with use, made more productive as they are farmed. That soil deterioration is neither inevitable nor necessary, if this harmony with nature is observed. That there is a choice.

Now it is interesting that all this talk about the balance and harmony of nature does not come from poets, philosophers, artists, or mystics. You might expect it from poets. But this talk comes from scientists in the field and laboratory men who are supposed to be hard-headed, cold-blooded, and other uncomplimentary things. When they begin to say that nature does have a harmony, which man must learn to respect and which he cannot break without suffering for it, it is time for people to sit up and listen. And that is exactly what they are saying They are not saying it in sonnets but in terms of the physical structure of soil, rate of percolation and run-off of water, colloidal chemistry, base exchange, phosphate fixation, bacteriological activity, and so on There may be no rhyme, but there is a powerful lot of reason in what they say

This would be interesting enough, this search for the harmony of nature as it is revealed in the soil, but you men working in soil science and agronomy are going further. You are trying to discover how man can conduct his affairs so that he in turn will live in harmony with this harmony of nature As I interpret your work, you say that this is what we must learn to do or else—or else expect a decline in rural welfare, and with this decline, destruction of this most basic of all our natural resources.

So you are trying to discover how, granting all the complex needs of civilization, we can still live in harmony with relatively simple laws that are rooted in the very nature of the earth. You are confident that you can discover how to do this, and in fact you have already made considerable progress in that direction. Your work, the work of plant breeders, pathologists, bacteriologists, engineers, and soil scientists, is showing results now in changed agricultural patterns in many areas here in the United States. I need not say what those changes are; you are all familiar with them. Some of you may be a little impatient and think the changes are proceeding too slowly. Some of you may be cautious and think they are proceeding too fast; but I believe any unbiased observer, looking over what is being done in the way of improving soil practices here in the United States, would be impressed with the fact that things are moving, and moving in general in the right direction.

There is another thing to be noted here. In this practical applica-

tion of your findings to the actual pattern of agriculture, you are stepping more or less outside your own field, or at least outside your field as soil scientists and agronomists. It would be—well, I won't say an easy matter, but perhaps it might be a comparatively easy matter, for you to outline some ideal system of soil management that would be in complete harmony with what we know of the physics and chemistry and biology of the soil. It is conceivable that a scientist who saw very clearly what should be done with the soil might be very impatient with the stupidity of men and feel that they should be forced, universally and forthwith, and for their own salvation, to act in accordance with the truth he saw. I am not saying there is any such scientist; I am saying it is conceivable that there might be. And he would be wrong. For in his preoccupation with the forces of nature in his own field, he would be completely disregarding the forces that operate in the field of human activity. He would simply be putting the reverse English on what those people are doing whose stupidity he condemns. They are preoccupied with their own human interests—the necessity to make a living, maybe even the desire to get rich—and they may not understand nor regard the ways of the soil. He may know a lot about the soil, but he neither understands nor regards the ways of people.

Now I have noticed an increasing emphasis on this point in the writings of soil scientists themselves. In the Soils Yearbook, for example, several authors stress again and again the relationship of price fluctuations, agricultural credit, tenancy, and rural electrification to soil conservation and use. I am told, not only by economists but by soil scientists themselves, that a reasonable stabilization of farm prices, for example, is absolutely essential for a soil conservation program of general significance. This growing appreciation, on the part of the scientist, of a wider frame of reference within which he must work if he hopes to achieve practical results seems very significant to me. During these past few years many of us have seen the errors of oversimplification—errors made by seeking answers to our agricultural problems in terms of one or of another specialty.

This leads me to another thought. We all know that within our country there are great variations in climate, in geological formations, and in soil, just as there are differences in ideas and institutions from place to place. One has only to think of agriculture in Maine, in the Dakotas, in Florida, or in Arizona to appreciate the enormous contrasts. Even within many of the states there are differences of profound significance. In reality, American agriculture consists of many agricultures. Thus, if we achieve a satisfactory harmony between soil and society there will necessarily be differences in both the physical and the institutional technics best suited to the various parts of the country. Not only has each community a more or less distinctive pattern of soil types but an individual pattern of ideas as well. All of these ideas add up to American culture and American democracy. Thus our agriculture must not only harmonize nationally, but on the local community level as well.

Our agricultural problems cannot be solved, in my judgment, with either extreme of centralization or decentralization. We know that the

American type of democracy depends upon the initiative, responsibility, and the freedom of thought of our citizens. With equal certainty we know that certain phases of our problems can only be met through cooperation for the common good. Some particular problems, such as soil conservation for example, may call for a large measure of community planning and local control, while others, such as price stabilization, may call for a greater degree of national responsibility. I regard the development of a proper balance between local autonomy and national solidarity to be a problem of the highest importance. The Department of Agriculture and the Land Grant Colleges have tried to meet this problem squarely with the development of the County Agricultural Planning Committees and State Advisory Councils. This plan, or something very like it, would seem to offer the opportunity for strengthening our democracy and increasing its usefulness at the same time. Its success or failure will be as significant to the scientists as to the farmers

In broader terms, the harmony and balance that the soil scientists are now stressing is only part of the story. It must be fitted into a bigger harmony that includes the nature of man and society. The tuning must be on a grand and comprehensive scale or there will be discord. We may achieve perfection in the part, but it will be utterly useless unless it fits in with the whole.

Now I said a few moments ago that the emphasis some of you scientists have been placing on the harmony and balance of nature encouraged me in some of my own beliefs. We have been damaging the soil because we have ruthlessly disregarded this balance. It is imperative that we discover what this balance is and bring it about. That is what you are trying to do now. Now it is my belief that something of the same thing has occurred in human affairs. We have developed a commercial civilization in an extreme form, and we were able to push it to these extremes because of the development of modern science and technology. Modern science is a new thing in the world, not known to man for the previous tens of thousands of years of his existence. It enabled him, using part of his brain, to develop a terrible efficiency within narrow limits. And he did develop that efficiency. But the question is whether, in doing this, he has not ruthlessly disregarded a natural balance of his own nature.

You can see the analogy I am drawing. We achieve perfection, relatively speaking, in a part of man's affairs, the part concerned with the technology of production. But it is useless because it does not fit in with the whole. We do not yet understand what the harmony of the whole is. But it is imperative to find out and to restore the balance, just as it is imperative for you to discover the balance of forces operating in the soil and work out practical methods of maintaining it.

To discover these broader, inclusive harmonies is a function of what has been called a new science of man, of which all other sciences will be a part in so far as they relate to human affairs. Whether we shall ever truly develop such a science of man, or whether the human race is capable of developing it, is more than I shall venture to say.

Excellent beginnings of such a science already exist in physiology, medicine, psychology, and anthropology. Perhaps these sciences will

fill the gap left by the sciences that have taught us how to produce abundance, but not how to distribute it or how to live at peace with ourselves and our environment while producing it. And, on the other hand, it is possible that we may destroy each other before we have a chance to develop such a science of man. I do believe that no effort is more worth while or more urgently needed, and the new emphasis on coordinating the natural sciences and the social sciences is a sign that the effort is being made.

Now I have been somewhat sidetracked, in spite of myself, from the theme I said I was going to discuss when I began this talk. Perhaps that is just as well. However, I am not going to neglect that theme entirely, especially since it fits in with what I have just been saying.

I believe—and before this audience I have tried to distinguish the field of belief from the field of fact; you see I am still wary of the Greeks bringing raspberries—I believe that in a good deal of our modern commercial farming we have gotten away from a certain very old harmony that fitted the nature of man very well. That harmony lay in the production of food and other products for our own group, by our own toil, from the land owned by the group. The group might be a single family or it might be larger than one family. This is perhaps the oldest pattern of human activity in producing the necessities of life; certainly it is the oldest pattern of agricultural activity. I do not need to prove that it harmonized with very deep age-old human needs and satisfactions. There is proof of a certain kind in the fact that wherever I go I find landless men who nurse a dream of some day having a patch of ground in the country and raising things on it for themselves. Many of them have never been on the land, but they regard themselves as exiles from it.

Well, the new pattern of commercial agriculture is diametrically opposed to this old pattern. It is a product of a civilization based on scientific technology, and it follows, roughly, the pattern of industrial production. In that pattern, no man produces anything complete for himself; in fact, a great many factories, even, do not produce anything complete. Each man produces a part of something that is a part of something else. Each specializes in a very limited kind of work Then each man receives a money wage— theoretically, at least—with which he can purchase the whole product when he needs it And this is the pattern imposed by technology on commercial agriculture. The commercial farmer, at least the ideal type of commercial farmer, never produces the ingredients of a whole meal He produces a part of a part of a meal Then, theoretically, he receives a money return for his labor which enables him to purchase enough of the products of other farmers to make a whole meal.

Now I am not going to argue the merits of this general arrangement. There are excellent arguments for it—all the arguments that deal with the advantages of specialization, division of labor, mass production, the peculiar suitability of certain regions for certain products, and so on. The pattern may be absolutely necessary and inevitable in our complex modern civilization, and it may have gotten us much farther than we could ever have gone without it, and raised our general

standard of living much higher than it would have been otherwise. I am not going to argue these points, although I think you will all agree that, having developed the technic, we have still an enormous amount to learn about distributing the products. What I do want to suggest is that, so far as agriculture is concerned, in applying the industrial pattern we have thrown out the baby with the bath. And I suggest that we ought to go out and bring the baby in again

The situation is most clearly evident, of course, in parts of the South. I don't need to enlarge on that before an audience of agricultural workers. The South has specialized in cotton for a long time, but under the old plantation system it also produced its own living, and in many cases, I suspect, a mighty good one; the reputation of Southern cooking certainly would not have developed if there had been nothing to cook The modern, more complete development of commercial cotton growing in the South, on the pattern of industrial specialization, was accompanied by a widespread abandonment of any adequate effort on the part of cotton farmers to feed themselves. Theoretically, according to the industrial technic, they should receive a money return that would enable them to buy plenty of food. But this has remained theoretical, at least during periods when there has been an especially bad breakdown in the distribution machinery. Meanwhile they found themselves both without the money to buy the food they needed, and without the food they might have produced by growing a little less cotton The baby and the bath both went out the window And this is by no means confined to the South. Babies and bathwater have been pitched out by farmers pretty well all over this country.

I think that farmers have been somewhat oversold on this industrial technic. I don't think that in agriculture it's quite all it's cracked up to be. The man who fastens eyelets made by somebody else onto a piece of leather cut by somebody else for a shoe that will be finished by somebody else that man doesn't have the tools or the material to make shoes for his own family. He doesn't even own the eyelets. But the average farmer does have the tools and the material and the land to grow his own food, and in most parts of the country he could do it without much trouble--if he wasn't oversold on the industrial technic. And my point is that he could solve this modern problem of distribution--or sidestep it, if you prefer - at least to the extent that he could feed his own family, and feed them well.

In other words, I see no good reason why, in farming, the new industrial pattern and the older agricultural pattern of self-sufficiency cannot exist side by side in the same place. In fact they will have to exist side by side unless we can solve the problem of commercial distribution better than we have. And I would go further than that. The old Persian astronomer-poet, Omar Khayyam, wrote in the Rubaiyat—

> "I sometimes wonder what the vintners buy
> One-half so precious as the stuff they sell."

Well, I am not the connoisseur of wine that old Omar was, but I would paraphrase the lines and say, "I sometimes wonder what the farmers buy, One-half so precious as the stuff they sell." That is especially true when I see farmers forced to sell the fertility of their soil for a pittance; when I see them selling food, and material for clothes, that they cannot buy themselves; when I see them selling a way of life that has harmonized with man's nature for thousands of years and getting what often looks like mighty little in return.

Now this paper is already long enough, longer than I intended, but I must add a few more words at this point. I do not mean that we should abandon modern methods of production and go back to the ways of our ancestors. But in searching for ways to solve modern problems, as we all are, we should not overlook the possibility that we may have missed something very worth while in going to the other extreme as far as we have. That certainly occurred in the case of the commercial exploitation of our soil. What I should like to see would be a frankly experimental approach toward this possibility of infusing some of the older methods and values into the new. That means experiments in partly self-sufficient farming; in community industries; in producer and consumer cooperation; and perhaps in the decentralization of some large-scale industries so that more workers could be in contact with the soil. I believe that we might work out some very worth-while patterns, not entirely like the new and not entirely like the old, by experimenting in these directions.

And in this, you scientists in the research and practical fields would have much to contribute. There are problems to solve quite distinct from the problems of commercial farming. There are products to develop for home use, plant products and types of animals, with qualities different from those needed for the commercial market. There are techniques and tools to devise that will give home production some of the efficiency of commercial production. A little of this has been done; I think much more could be done. Not many scientists have applied their massive brains to these problems as yet, just as not many architects have applied their massive brains to the problem of designing good small homes for people of modest means. I hope more of them will.

AN ESTIMATION OF THE NUMBER OF TOP-CROSSED PLANTS REQUIRED FOR ADEQUATE REPRESENTATION OF A CORN VARIETY[1]

G. F. SPRAGUE[2]

IN certain corn breeding problems it is important to know how many plants of a variety are necessary to provide an adequate sample. In 1934, St. John[3] reported yields of 51 top crosses made reciprocally. The average acre yield of all crosses where the variety functioned as the seed parent exceeded that of their reciprocals (inbred × variety) by 3.93 ± 0.46 bushels—a highly significant difference. The individual differences were correlated in part, at least, with differences in seed condition. This suggests that the customary practice of producing top-crossed seed on the inbred parent may not provide an entirely adequate measure of the yielding ability of inbred lines. Variation due to seed condition could easily be eliminated by the consistent use of the variety as the female parent. This would require that the seed be produced by hand pollination and would be feasible only if the variety could be adequately sampled by ears from a very few plants.

Varietal sampling is also of importance in connection with investigations under way at the Missouri Agricultural Experiment Station on a combination of selfing and top crossing in the production of new inbred lines. In brief, this selfing-top-crossing technic requires the production of selfed and top-crossed seeds from each of the selected plants from an open-pollinated variety or F_2 of a hybrid. In the first year both types of seed can be produced on the selected plant by double pollination. The plant is first selfed and then, three or four days later, pollinated with a pollen mixture from a variety possessing a different genetic constitution for endosperm color. This permits the separation of selfed and hybrid seed on the basis of xenia. Comparative yield tests of the hybrid seed measure the yielding potentialities of the selected plants. These tests are analagous to the old ear-to-row tests.

The ear-to-row method of breeding was found to be ineffective, partly because high-yielding ears were hybrids of unknown composition which could not be duplicated, and partly because in actual operation the narrow selection practiced resulted in inbreeding, which reduced yields. In our procedure the production of selfed seed maintains the identity of plants tested and avoids the first difficulty. Jenkins[4] has presented evidence indicating that differences in the

[1]Cooperative investigations of the Missouri Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Missouri Agr. Exp. Station Journal Series No. 569. Received for publication October 11, 1938.

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[3]ST. JOHN, R. R. A comparison of reciprocal top crosses in corn. Jour. Amer. Soc. Agron., 26:721–724. 1934.

[4]JENKINS, M. T. The effect of inbreeding and of selection within inbred lines of maize upon the hybrids made after successive generations of selfing. Iowa State College Jour. Sci., 9:429–450. 1935.

hybrid-combining abilities of lines may be determined in the early generations of inbreeding. In the selfing-top-crossing system each generation of selfing is alternated with a yield test of the top-crossed seed of selected plants. The theoretical advantages of this procedure are its provision for selection both on the basis of yielding ability and visual characteristics, and also for the elimination of low-yielding strains early in the inbreeding program. Thus, in each generation of inbreeding after the first, further selection and testing is confined to the known high-yielding portion of the population rather than to a random sample, as is the case with the usual inbreeding methods. Although the method has been practiced by us since 1934, successive droughts have prevented an adequate test of its usefulness. Its theoretical advantages justify an extensive study of its practical possibilities.

After the first or second generation of selfing, the ears of selected plants are too small to furnish adequate quantities of both selfed and top-crossed seed. Under these circumstances it is necessary to produce top-crossed seed by using an open-pollinated variety, or some suitable hybrid tester, as the female parent. When this procedure is followed the number of plants required adequately to sample the seed parent is important. The present report is concerned with an investigation to determine the variance among the top crosses on the ears of individual plants of a variety as a basis for computing the number of plants required in samples to reduce effectively the variance among sample means to a point where it becomes negligible when compared with the variance ascribable to random error

MATERIAL AND METHODS

The experimental material consisted of top-crossed ears of two varieties. The first lot (experiment A) included 40 ears of Reid Yellow Dent subdivided into two 20-ear samples. A plant of open-pollinated Reid was used as the male parent to make one set of 20 top-crossed ears and a plant of a long-time inbred line served as the male for the other set.

The second lot (experiment B) consisted of six samples of 20 top-crossed ears made within the variety Krug.[5] Each 20-ear sample had as its male parent a plant from a progeny grown from a first generation self. Thus, six different plants were used as males to pollinate the 120 ears. The two lots of seed, Reid and Krug, represent unselected samples except for the one limitation that only ears having 300 or more kernels were used. Since the seed was produced by hand pollination, there is no necessary relation between the number of kernels produced and the potential size of the ear.

The top crosses on plants of the two varieties (40 plants of Reid and 120 plants of Krug) were compared for yield in separate experiments. Fifteen replications of five hills each were planted from each top-crossed ear. Planting was in randomised blocks. Four kernels were planted per hill and later thinned to three plants where possible.

RESULTS

The analyses of variance for the plat yields of the two experiments ear presented in Table 1. In experiment A the variance among the

[5]The writer is indebted to Dr. Merle T. Jenkins for this seed.

top-crossed progenies is highly significant. The variance due to progenies is further separated into two components, one degree of freedom being associated with the difference in male parentage and the other 38 degrees of freedom with the differences among the female-parent plants of the Reid variety The variance among progenies after removing the effect of the male parents is highly significant, indicating a real difference in yielding ability.

TABLE 1.—*Analyses of variance of the plat yields for the top-crossed progenies of 40 and 120 plants of Reid Yellow Dent and Krug, respectively.*

Source of variation	Experiment A (Reid)			Experiment B (Krug)		
	Degrees of freedom	Sum of squares	Mean square	Degrees of freedom	Sum of squares	Mean square
Replications	14	135.34	9.67	14	485.97	34.71
Progenies	39	386.18	9.90*	119	537.91	4.52*
Male parentage	1	6.61	6.61	5	119.81	23.96*
Female parentage	38	379.57	9.99*	114	318.10	2.79*
Error (male parent × replications)	14	42.41	3.03	70	203.99	2.91
Error (female parent × replications)	532	1,115.65	2.10	1,596	2,527.32	1.58
Total	599	1,679.58	-	1,799	3,755.19	——

*Highly significant, exceeds the 1% point

The two male parents in this group were chosen to represent extreme differences in heterozygosity. It was thought that this difference in heterozygosity might indicate a difference in the number of plants required for adequate representation. However, the difference between the two male parents associated with only a single degree of freedom is not significant, falling short of the 5% point. When the progenies were tested for heterogeneity of variance by a method suggested by Brandt,[6] the value for X^2 (Chi^2) was found not to be significant.

In experiment B the variance due to progenies is highly significant. When this variance is subdivided into the portions due to male and female parentage, each portion likewise is highly significant. It is evident that both the male parents and the female parents differed significantly in their transmission of yielding ability. In an analysis of variance of stand, only the variance due to differences in male parentage was significant. This and an analysis of the covariance between yield and stand indicates that part of the differences in the

[6]The writer is indebted to Dr. A. E. Brandt for a description of this method prior to its publication. The method is based on the fact that $X^2 = \frac{(n-1)v}{u}$, where v represents any observed variance among n variances and u is their theoretical variance. In the present case a significant X^2 value indicates that the yield variances of the several top-crossed plants differ more than would be expected by random sampling from a uniform population of variances. A short description of the method is presented in Snedecor's *Statistical Methods*, pages 196, 197.

yields of progenies of the six males was due to their differential transmission of germinative ability. Use of the covariance between stand and yield permits a reduction in the error variance in this experiment from 1.58 to 0.98.

The observed variations in yield among the individual ears in these experiments are of interest in connection with the system of breeding outlined in the first part of this paper. In experiment A the mean yield was 55.5 bushels per acre, with extremes ranging from 40.1 to 71.2 bushels. In experiment B the mean yield was 45.4 bushels, with extreme yields of individual ears ranging from 26.9 to 62.8 bushels per acre. The highest yielding entry represents an increase in yield of 28.3 and 38.3% above their respective mean yields.

The wide spread in yielding ability among individual ears in each of these varieties suggests that a system of breeding which will permit of the concentration of efforts on the highest yielding plants and their progenies should result in a considerable increase in efficiency. The efficiency will be greatest in the first generation of selection and will decrease with each generation of inbreeding.

An estimate of the number of plants of the open-pollinated varieties required for adequate representation was obtained in the following manner. In experiment A the variance due to experimental error is 2.10. The variance among progenies of the Reid plants is 9.99, leaving 7.89 as the additional variance among progenies. For a 10-plant sample, the expected variance then would be 7.89/10+2.10 or 2.89. The data presented in Table 2 were calculated in this way. Estimates of the number of plants required for adequate representation have been computed before and after adjusting yield on the basis of its regression on stand.

TABLE 2.—*Calculated variances between female progenies for samples of various numbers of progenies on the basis of observed variances among the top-crossed progenies of individual plants.*

Plants per sample	Calculated variance			
	Experiment A		Experiment B	
	No stand correction	Corrected for stand	No stand correction	Corrected for stand
1	9.99	10.14	4.52	2.25
5	3.68	3.62	2.17	1.23
10	2.89	2.81	1.87	1.11
15	2.63	2.53	1.78	1.06
20	2.49	2.40	1.83	1.04
25	2.42	2.32	1.70	1.03
30	2.36	2.26	1.68	1.02
50	2.26	2.15	1.64	1.01
100	2.18	2.07	1.61	0.99

The results from the two experiments are in general agreement. In experiment B it appears that 10 plants would probably form an adequate sample. Increases in sample size above 20 plants result in

very slight reductions in the calculated variance The variance associated with error and with progenies is considerably higher in experiment A than in experiment B. However, in this case also 10 to 20 plants would provide a fair sample. Increases in sample size above 20 plants do not result in important reductions in the calculated variance. For the majority of experiments, it appears that a 10-plant sample would be entirely adequate.

In the calculations presented in Table 2 it has been assumed that the use of means would give essentially the same result as the use of a bulked sample. The error variance should be essentially the same in both cases, providing the size of plats and number of replications remains unchanged. One might expect that the variance associated with female parentage would be materially reduced by the use of a bulked sample since plat variability would also be reduced. The design of this experiment would doubtlessly have been improved by the inclusion of a series of bulked samples made up from various combinations of individual ears. It was not possible to do this because of the limitation imposed by the number of seeds per ear.

These calculations of the theoretical variances of samples of various sizes assume that each plant is equally represented. Since the usual practice is to bulk the seed from the top-crossed ears and to prepare planting samples from these bulked lots, it was first thought that this might introduce a serious error since it superimposes a second sampling problem.

The importance of this source of error has been examined. The following assumptions form the basis for these calculations: A 20-ear sample, each ear having 200 kernels, is bulked to give a total of 4,000 kernels. The size of the theoretical sample to be drawn was set at 20 kernels, because of the labor involved in expanding the binomial $(.05 \times .95)$, though the usual sample size for a single replication would be 60 to 100 kernels. With these limitations, the mean value to be expected is that in each 20-kernel sample a particular ear will be represented by one kernel. This is a Poisson distribution; consequently, the variance is equal to the mean, being 1. This indicates that, as a rough approximation, considering the 5% level of significance, one might expect the means of actual samples to fall within the range of $1 \pm .439$. Since this distribution is so highly skewed, it may be preferable to calculate the probability from $.95^{20}$ or .36. This value (.36) indicates a much higher probability, one chance in three, that any particular ear may be excluded from the 20-kernel sample. It is apparent, on the basis of either estimate, that no serious error will be introduced by sampling from bulked lots of seed.

In actual practice, the individual ears will not have equal numbers of seeds and will contribute in differing amounts to the bulked sample. In the absence of some serious bias, each ear will tend to be drawn in the same proportion that it contributes to the total sample. This would not be a serious source of error if more than 10 ears were used, unless several of the ears are represented by relatively small quantities of seed.

CONCLUSIONS

A study of the variance among the top crosses on individual plants of two open-pollinated varieties in relation to the variance associated with random error indicates that the variance of the means of samples of 10 to 20 plants will be unimportant, as compared with the variance ascribed to random error.

The preparation of seed for planting from bulked seed from this many plants would not introduce serious errors unless the size of the samples drawn from the bulked lot is small or the individual plants contribute widely different numbers of seeds to the total population.

THE EMERGENCE OF GRASS AND LEGUME SEEDLINGS PLANTED AT DIFFERENT DEPTHS IN FIVE SOIL TYPES[1]

R. P. MURPHY AND A. C. ARNY[2]

DURING the last few years many farmers and experiment station workers have realized that the amount of seed planted of many of the grasses and small-seeded legumes was far in excess of the number of seedlings obtained in the initial stand. Such experiences have probably been due to the effect of environmental influences, species of plant, depth of planting, soil type, and other less important factors upon the total emergence. Although these factors, with the exception of the environmental effects, may be controlled in part, the influences of any one of these factors or of the interactions among these factors have not been studied extensively by experimental methods.

Farmers have been sowing too deeply in some cases and some of the recommendations for depth of planting grasses and legumes found in the literature involve depths which were probably too deep for maximum seedling emergence. Since a good initial stand is necessary in the establishment of meadows and pastures, it was believed desirable to determine as definitely as possible the effect of the above variables upon the primary emergence.

REVIEW OF LITERATURE

Love and Hanson (2)[3] were among the first to study the effect on stand of different depths of planting. Their investigations were conducted in the greenhouse with crested wheat grass. Two hundred seeds were planted at several depths in clay soil of good tilth.

They observed that seed of crested wheat grass germinated well upon the surface of the soil when there was sufficient moisture. However, in the field, if the surface was dry, the best depth at which to plant was usually between one-fourth and one-half inch depending upon the dryness of the surface soil.

Love and Hanson (2) reported a similar experiment with brome grass. They concluded that the maximum depth at which emergence occurred was 3 inches. Five per cent of the seedlings emerged at this depth. About 65% of the seedlings emerged from 1/8 to 1 inch plantings.

Kirk, Stevenson, and Clarke (1) report depth of seeding studies with crested wheat grass which were carried out in the greenhouse. A similar field test showed clearly that in both spring and fall seedings the best stands were obtained from the ½-inch depth of planting. They state that planting too deeply has been responsible for many failures with this crop in Saskatchewan.

McMichael (3), in a study to determine the most satisfactory depth at which to plant a number of species of grasses, found that brome grass gave good stands

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[3]Figures in parenthesis refer to "Literature Cited", p. 28.

down to and including the 2-inch depth. The emergence was good for the fairway and forage strains of crested wheat grass at ½ inch or shallower depths with only 50% emergence at the ⅛ inch depth of planting. Kentucky bluegrass produced the best stand from the surface planting while the ½ inch planting gave a very poor emergence.

The rate of emergence was also determined for these grasses by McMichael. Nearly all the plants of brome grass and crested wheat grass emerged between 5 and 15 days after planting, but the majority of the Kentucky bluegrass seedlings required from 10 to 20 days to emerge.

Stevenson (4) recently reported that in Saskatchewan deep seeding has been responsible for many failures with sweet clover. He found that 1 inch was the maximum planting depth even on the lighter soil types.

MATERIALS AND METHODS

Five important soil types which occur commonly in Minnesota and which vary widely in texture were obtained for these studies. The types selected included Carrington heavy silt loam and Clinton silt loam from Fillmore County, Clarion silt loam from Redwood County, Fargo silty clay loam from Wilkin County, and Merrimac loamy fine sand from Ramsey County. These soils taken from the surface 6 inches were brought to University Farm in the summer of 1936.

The moisture equivalents and pH values of these soil types are given in Table 1.

TABLE 1.—*The pH values and moisture equivalents of the soil types used in this study.*

Soil type	pH	Moisture equivalent %
Merrimac loamy fine sand.	6.7	6.89
Clinton silt loam ..	6.2	20.35
Carrington heavy silt loam	5.6	24 18
Clarion silt loam...... .	6.0	26.24
Fargo silty clay loam	6.7	34.16

The Merrimac loamy fine sand dried rather quickly following watering because of the low water-holding capacity. However, the surface of this soil did not crack since it was very low in colloidal material. The surfaces of the Carrington heavy silt loam and especially of the Clinton silt loam remained damp for some time after watering. This may be explained by the rather high moisture equivalent combined with a rapid rise in capillary water due to the high content of silt. The surface did not crack badly as the soils were not high in colloidal matter. The Clarion silt loam reacted much the same way but dried out faster on the surface. The Fargo silty clay loam, however, was very different. The surface dried rapidly, often in one day, after rains or watering, but the deeper layers remained very wet. The high moisture equivalent permitted the soil to hold a high percentage of water, but the slow capillary movement due to a high content of clay, did not maintain a moist surface. In addition, the surface cracked severely because of the high content of colloidal matter. During the course of these experiments none of these soils developed a heavy crust which the seedlings were unable to penetrate.

The crop seeds used in the studies in both the greenhouse and field included, Grimm alfalfa, biennial white sweet clover, red clover, alsike clover, white clover,

timothy, brome grass, forage crested wheat grass, reed canary grass, and Kentucky bluegrass. Crop seeds used in the greenhouse studies only included sudan grass, Red Turghai millet, German millet, slender wheat grass, perennial rye grass, meadow fescue, orchard grass, and red top.

The percentage of germination was determined so that the same number of viable seeds could be planted for each crop at each depth. The studies were made in the greenhouse and in the field. The greenhouse experiments were made to obtain results for optimum conditions for emergence. The field studies were made to obtain results on emergence similar to what might be expected under actual field conditions.

Flats 16 inches square and 6 inches deep were used in both the greenhouse and the field studies. In the field, the surface soil was removed to a depth of 6 inches and flats without bottoms were fitted into place. These were then filled with the different soils and allowed to remain over winter before any plantings were made.

The depths of planting used in these studies were as follows: Surface, ½ inch, 1 inch, 2 inches, and 3 inches. These were determined accurately by removing the soil to the desired depth, followed by planting and replacement of the soil. The soil was packed slightly in an effort to approximate normal planting conditions. The surface planting was sprinkled lightly with soil to hold the seeds in place during rains or watering.

Notes on the emergence were taken each day after planting until no further seedlings appeared; consequently, the data collected include the rate of emergence for the variables as well as the total emergence.

Although the results for the emergence under field conditions are for only one season, the data are an average of two dates of planting with somewhat different environmental conditions prevailing during the times of emergence. The first planting, made May 4, developed under cool temperatures and a total precipitation of 4.23 inches which fell on seven different days The surfaces of the soils were somewhat moist at all times. The second planting, made June 7, developed under variable environmental conditions. The soils were moist and in excellent tilth at planting time, but during the time of emergence the temperature was quite variable with five days over 80°F. During the time of emergence, only two rains fell, 1.38 inches on June 13 and 1.29 inches on June 17. However, as the results for the total emergence were very similar for the two dates of plantings, the field tests were summarized together.

At the conclusion of the greenhouse studies, the seed weights were correlated with total emergence from the five depths of planting. The weight of seeds was determined by an average of three separate lots of 1,000 seeds.

RESULTS

In these studies some of the differences in emergence among the legumes may be explained by the attacks of some of the "damping-off" fungi at the time of emergence or pre-emergence. This effect was more noticeable in the greenhouse than in the field. Sweet clover was the most severely affected, while red clover showed the least injury.

In Table 2 are given the results of emergence of seedlings for each crop from each depth of planting for the tests made on Carrington heavy silt loam.

TABLE 2.—*Percentage of total emergence from Carrington heavy silt loam*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	80	69	46	4	0	81	73	48	19	0
Sweet clover	68	54	30	0	0	65	51	43	12	0
Red clover	86	85	77	2	0	87	86	70	12	0
Alsike clover	80	75	29	0	0	74	64	51	0	0
White clover	87	67	40	0	0	88	76	54	0	0
Timothy	86	81	56	0	0	84	85	68	3	0
Brome	98	100	94	46	3	100	100	100	80	20
Crested wheat	82	82	58	4	0	82	84	73	21	0
Reed canary	82	87	70	37	1	93	84	76	54	17
Kentucky blue	56	46	9	0	0	83	62	24	0	0

As the surface of this soil type remained moist for some time in the field, the maximum seedling emergence for most of the crops came from the surface plantings and was very similar to the results in the greenhouse where conditions were most favorable. Kentucky bluegrass was the only notable exception to this as the emergence from all depths was much lower in the field than in the greenhouse, indicating that this crop was influenced more by changes in environmental conditions than were the other crops. Emergence from the ½ inch depth of planting was similar to that from the surface planting. Sweet clover, alsike clover, white clover, and Kentucky bluegrass seedlings did not emerge satisfactorily from the 1-inch planting in the field. From the 2-inch depth in the field the seedling emergence for brome grass was 46% and for reed canary grass 37%. The results from this depth were much higher for these crops in the greenhouse. The 2-inch plantings of brome grass in the field were fairly satisfactory.

The results from all tests from Clinton silt loam are given in Table 3.

TABLE 3.—*Percentage of total emergence from Clinton silt loam*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	77	70	34	4	0	66	52	31	0	0
Sweet clover	66	65	26	0	0	53	35	21	0	0
Red clover	86	78	48	3	0	72	65	45	0	0
Alsike clover	76	59	18	0	0	65	22	7	0	0
White clover	84	72	22	0	0	78	50	25	0	0
Timothy	92	68	32	0	0	88	60	49	0	0
Brome	100	95	81	32	1	100	100	98	36	3
Crested wheat	84	70	32	0	0	79	61	50	2	0
Reed canary	86	77	58	20	6	86	80	71	36	4
Kentucky blue	66	53	0	0	0	81	49	16	0	0

The best results on this soil type were also obtained from the surface planting since the soil remained moist long after rains or watering The continually moist surface did not permit the soil to crack or crumble with the result that the seedbed became rather firm. Consequently, the total emergence from the deeper depths was low Only brome grass, reed canary grass, and red clover gave an appreciable emergence from the 1-inch plantings in the field Satisfactory emergence was not obtained from the 2-inch plantings in any of the tests with this soil type

In Table 4 are found the average results from emergence from Clarion silt loam

TABLE 4 —*Percentage of total emergence from Clarion silt loam*

Crop	Depth of planting inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	84	74	14	4	0	72	50	35	14	0
Sweet clover	70	64	15	4	0	58	44	35	11	0
Red clover	82	86	48	12	0	86	80	71	16	0
Alsike clover	69	72	18	0	0	67	58	46	0	0
White clover	82	80	24	0	0	88	76	65	1	0
Timothy	82	75	38	0	0	87	83	74	10	0
Brome	90	100	86	55	21	100	100	100	91	39
Crested wheat	70	73	54	8	0	88	79	71	16	1
Reed canary	63	80	68	29	3	97	88	81	66	24
Kentucky blue	39	38	6	0	0	89	70	33	0	0

Since the surface of this soil becomes more open and friable soon after rains or after watering, the results were somewhat different from those on the Carrington and Clinton soil types In general, the ½-inch planting in the field produced an emergence as high or higher than that from the surface planting Reed canary grass in the field tests gave a much higher percentage of emergence from the ½-inch plantings than from the other depths Red clover produced a 48% emergence and brome grass, crested wheat grass, and reed canary grass produced an even higher percentage of emergence from 1-inch plantings in the field A 55% emergence of brome grass was obtained from the 2-inch depth in the field In the greenhouse, the emergence from the deeper depths was much higher than in the field From this soil, 21% of the brome grass seedlings emerged from the 3-inch depth in the field which was much greater than the emergence on the Carrington or Clinton soil types from this depth

The results from Fargo silty clay loam are given in Table 5 for all tests

As the surface of this soil type dries very rapidly, the emergence from the surface plantings in the field was low for all crops However, 75% of the brome grass, 72% of the crested wheat grass, and 70% of the alfalfa emerged under these conditions In contrast to this, 26% of the reed canary grass and only 12% of the Kentucky bluegrass emerged

TABLE 5.—*Percentage of total emergence from Fargo silty clay loam.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	70	82	61	22	2	80	66	66	45	0
Sweet clover	54	63	51	16	3	66	52	39	19	0
Red clover	59	82	78	23	1	88	80	76	14	0
Alsike clover	43	73	47	0	0	84	56	46	0	0
White clover	46	85	58	0	0	89	76	72	0	0
Timothy	58	68	36	0	0	86	79	66	2	0
Brome	75	98	97	83	42	100	100	100	90	51
Crested wheat	72	74	55	9	4	92	73	69	24	2
Reed canary	26	78	80	28	7	96	92	86	54	26
Kentucky blue	12	37	3	0	0	80	62	24	0	0

from the surface plantings in the field. Thus, the data in these studies indicate that brome grass, crested wheat grass, and alfalfa seeds germinated and emerged better under drier soil conditions than were favorable for the other seeds. The emergence was highest for all crops planted ½-inch deep except reed canary grass which produced a slightly higher emergence from the 1-inch planting. Fair to good emergence from the 1-inch depth was noted for all crops except timothy and Kentucky bluegrass. In the field, brome grass gave 83% emergence from the 2-inch depth and 42% from the 3-inch depth of planting. Twenty-two per cent emergence occurred for alfalfa, 23% for red clover, and 28% for reed canary grass from the 2-inch planting in the field on this soil type. On the basis of these results somewhat deeper plantings appear to be advisable on this soil type than on the others tested in these experiments.

Emergence in the greenhouse was high from all depths and for all crops on this soil type. However, as shown by the field results, environmental conditions usually occurring in the spring probably will make the ½-inch plantings on this soil type the most desirable for all the crops tested in these studies.

The results in Table 6 are for the average emergence from Merrimac loamy fine sand.

The emergence from this soil type in the field was lower from the surface than from the ½-inch planting for all crops except alfalfa and Kentucky bluegrass, but the difference was not as great as with the Fargo silty clay loam. Reed canary grass gave only 51% emergence from the surface planting but 80% emergence from the ½-inch planting. Red clover, timothy, brome grass, crested wheat grass, and reed canary grass were the only crops to produce over 50% emergence from the 1-inch depth. Brome grass was the only crop in the field to give a satisfactory emergence from the 2-inch depth which was 63%. In the greenhouse the highest emergence was from the surface plantings. The 1-inch planting in the greenhouse showed over 50% stand only in the case of red clover, brome grass, reed canary grass, and crested wheat grass. In general, in no tests was the emergence of

TABLE 6.—*Percentage of total emergence from Merrimac loamy fine sand.*

Crop	Depth of planting, inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	74	73	44	4	0	79	52	30	0	0
Sweet clover.	64	65	31	2	0	82	46	29	0	0
Red clover .	74	81	64	0	0	80	80	59	0	0
Alsike clover .	59	65	20	0	0	66	42	14	0	0
White clover .	58	76	25	0	0	77	66	30	0	0
Timothy....	52	80	56	0	0	79	67	48	0	0
Brome.. ...	82	99	91	63	16	100	97	94	80	32
Crested wheat	70	75	61	10	0	76	70	57	11	0
Reed canary.	51	80	67	22	1	88	72	68	51	26
Kentucky blue	32	30	6	0	0	82	63	18	0	0

seedlings higher from this sandy soil than from the other soil types except from Clinton silt loam.

In Table 7 are given for each crop the average results of emergence for all soil types from each depth in order to compare only the differences shown by the crops.

TABLE 7.—*Summary of percentage of total emergence from all soil types.*

Crop	Depth of planting inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Alfalfa	77	74	40	7	0	76	59	42	16	0
Sweet clover	64	62	30	4	1	65	45	34	8	0
Red clover . .	77	82	63	8	0	83	78	64	9	0
Alsike clover	65	69	27	0	0	71	40	33	0	0
White clover ...	71	76	34	0	0	84	69	49	0	0
Timothy.. .	74	74	44	0	0	85	75	61	3	0
Brome.. ..	89	98	90	56	12	100	100	99	75	29
Crested wheat	76	75	52	6	1	83	74	64	15	1
Reed canary	62	80	68	27	3	92	83	76	52	19
Kentucky blue	41	41	5	0	0	83	61	23	0	0

The total emergence from the surface and from the ½-inch plantings was satisfactory for all crops in these averaged field tests. The only crop which showed a definitely lower emergence for the surface than for the ½-inch planting was reed canary grass. Red clover was the only legume in these studies which averaged more than 50% emergence from the 1-inch depth of planting. Brome grass and reed canary grass gave a satisfactory emergence at the 1-inch depth of planting, while crested wheat grass showed a fair emergence of 52%. From the 2-inch depth of planting only brome grass showed emergence greater than 50%. The summary of the total emergence in the greenhouse showed what might be expected in the field under ideal

conditions. Under the greenhouse conditions in these tests, plantings at the surface and ½-inch depths were satisfactory for all crops with red clover, brome grass, reed canary grass, and crested wheat grass producing good results from the 1-inch depth. Brome grass and reed canary grass showed over 50% emergence from the 2-inch plantings in the greenhouse

After the above summaries had been obtained there appeared to be some correlation between emergence from the greater depths of planting and weight of seed. Since this association seemed to be rather constant for the emergence in the greenhouse and field, eight more grasses which were tested only in the greenhouse on all soil types were used in order to have a greater range of weight of seeds In Table 8 are given the results of the correlation study between weight of seed for each crop and the average total emergence from the different depths in the greenhouse on all soil types

TABLE 8.—*Correlation of seed weight with total emergence from five depths of planting*

Crop	Weight in grams of 1,000 seeds	Percentage emergence in greenhouse at different depths				
		0	½ in.	1 in.	2 in	3 in.
Alfalfa	2 17	76	59	42	16	0
Sweet clover	1 91	65	45	34	8	0
Red clover	1.62	83	78	64	9	0
Alsike clover	0 71	71	49	33	0	0
White clover	0.68	84	69	49	0	0
Sudan grass	9 64	79	63	57	51	47
Red Turghai millet	4.45	78	68	63	47	48
Brome grass	3.57	100	98	95	75	34
German millet	2.80	76	66	70	58	47
Slender wheat grass	2.45	93	92	88	69	33
Crested wheat grass	2.02	83	74	64	15	1
Perennial rye grass	1 93	99	96	96	87	69
Meadow fescue	1 58	94	89	81	52	13
Orchard grass .	0.87	76	57	45	11	0
Reed canary grass	0 84	92	83	76	52	19
Timothy.	0.41	85	75	61	3	0
Kentucky bluegrass	0.21	83	61	23	0	0
Redtop. .	0.11	80	60	38	0	0
D.F. = 16 Calculated r Significant r .4683		-.029	.057	.246	.473	.600

The correlation coefficient was considered significant when the odds were 19:1 or greater that this difference did not occur because of chance alone. As is shown by the correlation coefficients, the weight of seeds was a significant factor in determining emergence in these tests only when they were planted 2 or 3 inches deep. However, the relationship at these depths is not linear. Perennial rye grass and reed canary grass gave emergences which are higher than would be expected from their seed weights. Likewise, crested wheat grass showed emergences which were distinctly lower than would be expected.

Consequently, the emergence from these depths for all crops probably should be determined experimentally

Additional results taken recently from greenhouse and field experiments showed that red top and orchard grass produced good stands only from the surface and ½-inch depths Sudan grass, German millet, Red Turghai millet, slender wheat grass, meadow fescue, and perennial rye grass emerged satisfactorily from the surface, ½- and 1-inch plantings Perennial rye grass, sudan grass, and the millets showed emergence as high as those for brome grass from the 2- and 3-inch plantings

The results in Table 9 are given to compare the differences in total emergence from each depth from the different soil types as an average of all crops

TABLE 9 *Summary of average total emergence for all crops at each depth in each soil type*

Soil type	Depth of planting inches									
	Field experiments					Greenhouse experiments				
	0	½	1	2	3	0	½	1	2	3
Carrington heavy silt loam	80	75	51	9	0	84	76	61	20	4
Clinton silt loam	82	71	35	6	1	77	57	41	7	1
Clarion silt loam	73	74	37	11	2	83	73	61	22	6
Fargo silty clay loam	52	74	57	18	6	86	74	64	25	8
Merrimac loamy fine sand	62	72	46	10	2	81	66	48	14	6

From Fargo silty clay loam and Merrimac loamy fine sand the total emergence in the field was definitely higher from the ½-inch than from the surface plantings

In the field, the emergence from the surface plantings was high on Carrington heavy silt loam and on Clinton silt loam Considering the 1-inch depth of planting only, the emergence was highest on Fargo silty clay loam in both the greenhouse and field tests and lowest on Clinton silt loam

In the greenhouse the total emergence was highest from the surface planting on all soil types The lowest percentage in the greenhouse at each depth was on Clinton silt loam In general the decrease in emergence from the surface to the 3-inch depth of plantings in the greenhouse was fairly constant for each soil type which would be expected under optimum conditions

Summary of the rate of emergence for each crop from each depth from each soil type is not given in detail as the mass of data was too great

The rate of emergence was more uniform in the greenhouse than in the field This difference was probably caused by the more variable environmental conditions in the field The rate of emergence in the field was influenced more by environmental changes at the surface planting than at the deeper depths From all depths in the field, the emergence was influenced greatly from day to day by temperature and moisture changes

Reed canary grass emerged much more slowly on Fargo silty clay loam in the field than in the greenhouse. The rate of emergence of the grasses in the field was somewhat slower on the Fargo silty clay loam than on the other soil types. In the greenhouse, the clovers tended to emerge most rapidly from the Merrimac loamy fine sand.

The rate of emergence in the greenhouse was more rapid for all crops from the surface planting than from the other planting depths. In contrast to these results the rate of emergence in the field was most rapid for all crops from the ½-inch depths of planting. From the same depths, brome grass and crested wheat grass reach maximum emergence sooner than reed canary grass and Kentucky bluegrass. No important differences in the rate of emergence among the legumes were observed in either the field or greenhouse tests.

A summary of the rate of emergence is given in Table 10 to show the average differences as groups between the legumes and grasses used in these studies. For each depth the percentage of the total emergence was calculated for each five-day period.

TABLE 10.—*Percentages of average total emergence of legumes and of grasses from all soil types from each depth by five day-periods after planting.*

Days	Field experiments									
	Legumes					Grasses				
	0	½ in.	1 in.	2 in.	3 in.	0	½ in.	1 in.	2 in.	3 in.
5	—	9	3	—	—	—	—	—	—	—
10	49	62	71	47	—	15	44	48	10	—
15	49	27	21	47	—	58	47	45	63	47
20	2	2	4	6	—	19	7	6	24	47
25	—	—	1	—	—	7	2	1	3	6
30	—	—	—	—	—	1	—	—	—	—
Total emergence	70	74	38	3	—	68	73	51	17	3
Days	**Greenhouse experiments**									
	Legumes					Grasses				
	0	½ in.	1 in.	2 in.	3 in.	0	½ in.	1 in.	2 in.	3 in.
5	66	40	13	35	—	6	1	1	—	—
10	31	57	79	53	—	82	84	81	46	6
15	3	3	8	12	—	11	13	15	46	69
20	—	—	—	—	—	1	2	3	7	25
25	—	—	—	—	—	—	—	—	1	—
30	—	—	—	—	—	—	—	—	—	—
Total emergence	76	60	45	7	—	89	79	66	30	10

In the greenhouse tests the legume seedlings emerged much more rapidly than the grass seedlings. Even under the less favorable conditions in the field, the legume seedlings emerged more rapidly. In addition, the total emergence of the legumes was attained over a shorter

period of time than with the grasses. This ability to emerge more rapidly should be a distinct advantage to the legumes in the field as favorable conditions for emergence would not be necessary for so long a time after planting as with the grasses.

SUMMARY AND CONCLUSIONS

The purpose of the experiments was to determine the effect of depth of planting of seed and of soil type upon the initial stand of a number of grasses and legumes, the majority of which are used in the pastures and meadows of Minnesota.

A study was made of the total emergence of the grasses and legumes from five depths of planting in five soil types. The rate of emergence was also taken for the same variables.

The depth of planting was found to be the most important factor which determined the total emergence of seedlings of the individual crops in these studies. Approximately ½ inch was a satisfactory depth at which to plant the species used in these studies, although the surface planting produced good stands under ideal conditions for emergence.

Timothy and crested wheat grass produced optimum stands in the field from the ½-inch depth while the 1-inch depth of plantings was not very satisfactory, especially on Clinton silt loam. Reed canary grass planted 1 inch deep produced good emergence on all soil types. Satisfactory emergence was obtained for brome grass from the 2-inch depth of planting on all soil types except Clinton silt loam.

Alfalfa and sweet clover produced uncertain stands at the 1-inch depth of planting in the field on all soil types except Fargo silty clay loam. The emergence was satisfactory for red clover at the 1-inch depth on all soil types.

From these results, it appears that brome grass can be mixed and seeded with grain crops if no other satisfactory method of seeding is available.

The seed weight of 18 species of grasses and legumes tested in the greenhouse on all soil types showed a significant positive correlation with the total emergence from the 2- and 3-inch depth of plantings.

Surface plantings gave the highest percentage of emergence for all crops on Carrington heavy silt loam and on Clinton silt loam.

In the field the total emergence was definitely greater from the ½-inch plantings than from the surface plantings on the Fargo silty clay loam and Merrimac loamy fine sand.

The total emergence from the deeper depths of planting was somewhat higher on Fargo silty clay loam than on the other soils and was lowest on Clinton silt loam.

If the depth of planting which gives the maximum total emergence is used for a given species, it should be possible to obtain a desirable stand by planting less seed per acre than has been practiced by farmers and often recommended by agronomists.

Environmental conditions were found to influence the rate of emergence in these studies more than the other variables. The emergence was nearly complete 15 days after planting for all species studied.

The legumes reached maximum emergence approximately five days before the grasses. These data indicate that desirable conditions for emergence must continue somewhat longer after planting for the grasses than for the legumes.

LITERATURE CITED

1. KIRK, L. E., STEVENSON, T. M., and CLARKE, S. E. Crested wheat grass. Dom. of Canada Dept. Agr. Pamphlet 157. New Series. 1934.
2. LOVE, L. D., and HANSON, H. C. Life history and habits of crested wheat grass. Jour. Agr. Res., 45:371–383. 1932.
3. MCMICHAEL, S. C. The relation between depth of seeding and emergence for certain grasses. Soil Conservation Service, Huron, South Dakota. (Unpublished.) 1934.
4. STEVENSON, T. M. Sweet clover in Saskatchewan. Univ. of Sask. Agr. Ext. Bul. 9. 1938.

DETERMINING BY PLANT RESPONSE THE RETENTION OF NUTRIENT IONS BY SOILS[1]

JOHN P. CONRAD AND C. N. ADAMS[2]

THE retention[3] or non-retention of ions or compounds bearing essential elements have until now been largely determined by the procedures of analytical chemistry. We may logically reason from experimental data so obtained that retention should often be reflected in plant response in the field. To demonstrate retention by plant growth primarily to make the teaching of this subject more concrete and more appealing was the object of the writers in starting this study. With the general validity of the method evaluated by the data contained herein, and other similar data, the senior writer has continued to use it as a research procedure in investigating the reactions of a number of nutrient-containing compounds with several soils. The results of these studies will appear later

A method for poisonous substances worked out by Crafts[4] was first tried. By allowing a solution containing a toxic material to drip slowly upon a continuous column of dry soil in a demountable tube, he studied the retention in the various levels of the column. After each column was wet to the bottom, it was sectioned transversely with the successive sections being placed in a series of cannery tins and subsequently cropped to oats. Retention was judged by the injury to the oats

In preliminary trials with this method $NaNO_3$, NH_4OH, and $(NH_4)_2SO_4$ were used as test solutions Plant response to the nitrogen contained therein demonstrated the non-retention of NO_3 ions, while the NH_4 ions were all retained in the very uppermost section of each of the respective soil columns. After these trials, a simplification of the procedure seemed desirable and at the same time possible without materially altering the results. In this simplification the writers have used an interrupted column of soil namely, a stack of pots, the drainage from the hole of one dripping down into the one below. This procedure introduces one more condition that makes it different from field conditions, but it has manifold manipulative advantages. Fig. 1 gives the main features of the procedure.

In comparing the two methods, it is evident that practically all of the operations in handling the discontinuous column of pots are necessary, also, in the continuous column of soil with the further disadvantage that in the latter case these must be carried on with wet soil instead of dry. A great number of other manipulations, necessary with the continuous column, are not required in the column of pots.

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[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication October 11, 1938.

[2]Lecturer in Agronomy and Senior student (1937), respectively.

[3]Way (as quoted by Russell: Soil Conditions and Plant Growth) used "retention" where the word "fixation" is now often used. We have followed Way's example to prevent possible confusion from the use of "fixation of nitrogen" as this term has been preempted for an entirely different concept.

[4]CRAFTS, A. S. The toxicity of sodium arsenite and sodium chlorate in four California soils. Hilgardia, 9:461-498. 1935.

Presenting the subject of ionic exchange in soils to two college classes and the subject of the interaction of soils and fertilizers to a large group of farmers has been greatly aided by the use of illustrative material of this kind. Principles discovered by Way in the laboratory in 1850 may thus be demonstrated by plant response.

PROCEDURE

The general procedure is shown in Fig. 1 and more of the details of weighing and other data in Table 1. Four-inch pots and cannery tins (No. 2½) were previously prepared for the columns and for subsequent growth by painting with asphaltum paint or varnish. Cannery-tin tops previously punched with large holes are used to hold the pots in the column apart (Fig. 1 lower left). A square of waxed paper with a little of the soil under one side is used to cover the hole in the pot.

Pots (5-inch likewise painted) equipped with needle-valves, each consisting of a one-holed rubber stopper plugged with a piece of glass tubing drawn to a long taper, act as reservoirs for the test solutions. The amount of solution in the reservoir sufficient to wet all of the soil in the column with a safe excess is increased accordingly if confirmatory analyses are to be made on the drainage water. The rate of dripping is regulated by raising or lowering the tapered tubing and is kept slow enough to prevent any but a little accumulation on top of the soil. After dripping is completed and the excess allowed to drain away, the columns are taken down and each pot is nested into its respective drainage tin. The drainage water at the bottom of the column is measured and discarded or saved for analysis. Often the weighings of pots (Table 1—d, e, f, g) are omitted but not the measuring of the drainage water.

TABLE 1.—*Some details of procedure and data recorded for Fig. 1 and Table 2.*

Date of Percolation: *March 11, 1938* Crop: *Double Dwarf milo*
Planted: *March 19, 1938* Randomized: *March 28, 1938*
Harvested: *April 20, 1938* Water: *Tap*

Column No. and treatment (a)	Pot No. (b)	No. in Col. (c)	Percolation pot weights, grams: Tare pot (d)	With soil: Dry (e)	With soil: Wet (f)	Grams H_2O retained (g)	Harvest: Height, cms (h)	Harvest: Wet weight, grams (i)	Harvest: Dry weight, grams (j)
1. H_2O	793	1	323	723	871	148	21.7	1.59	0.37
	794	2	324	724	863	139	22.5	1.61	0.36
	795	3	338	738	865	127	20.4	1.37	0.32
				Drainage ml		9			
450 ml added				Recovered		423			
8. $(NH_4)_2SO_4$	814	1	336	736	883	147	73.8	54.12	6.85
	815	2	340	740	876	136	19.0	1.28	0.32
	816	3	342	742	869	127	21.7	1.23	0.29
				Drainage ml		22			
450 ml added				Recovered		432			

Any screened and well-mixed lot of dry soil deficient in the nutrient element to be tested may be used, though a preliminary trial to determine how rapidly water moves through it helps to eliminate impervious soils. One silt loam and a fine sandy loam out of 14 different lots of soil have given difficulties of this kind. If a soil is deficient in more than one element, those not under test must be sup-

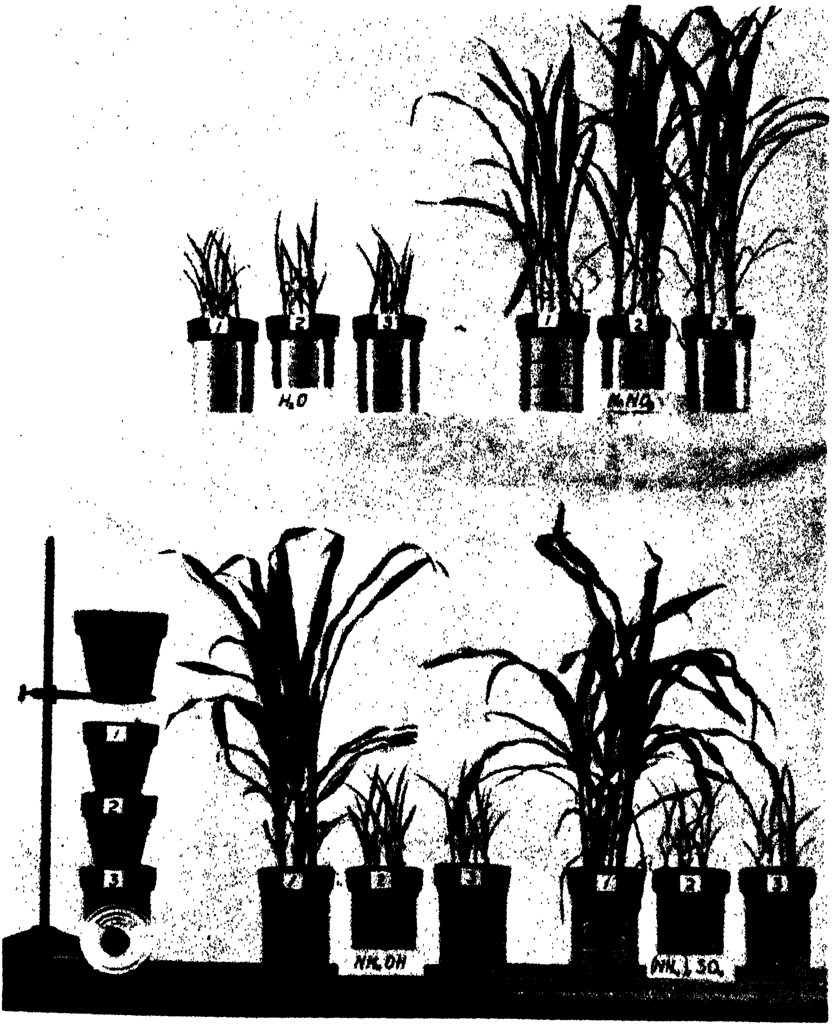

FIG. 1.—NITROGEN-RETENTION FROM PERCOLATING SOLUTIONS. *Method (lower left):* The percolating solution being tested, slowly drips from the larger (5 inch) pot at the top, down upon the column of three 4-inch pots (1, 2, and 3) each containing 400 grams of dry soil deficient in nitrogen and planted to milo. The milo is allowed to grow about one month after the columns are taken down. *Results (above):* The test solution used in each case is shown on the card leaning against pot No. 2 of that column. Thus the NO_3-ions of $NaNO_3$ are not retained by the soil, while the NH_4-ions of both NH_4OH and $(NH_4)_2SO_4$ are retained.

plied either as relatively insoluble or readily retained compound, e.g., K_3PO_4 for the soil in Table 2, added before percolation, or as a soluble and not readily retained compound, as urea or nitrates for Aiken and Huer Huero soils in Table 3, added in equal amount to each pot of a given test.

If the soil is light and the solutions to be used are not toxic, large seeds may be planted in the dry soil before percolation. This procedure saves considerable time and in a month's growth the short difference of time between wetting the seed in the top pot and in the lowest one is of no consequence practically. Ten seeds of milo per pot are usually planted. As soon as practicable these are usually thinned to six. Because of its very erect growth in the greenhouse, milo has been used as a test plant and has given satisfactory to marked responses to N, P, and S in pot cultures.

A pot with its drainage can serve much the same purpose as a Mitscherlich pot, as the drainage water is periodically returned to the pot. Excess waterlogging in all but impervious soils can be avoided by judicious watering, but the extreme care necessary with closed containers is not necessary.

EXPERIMENTAL RESULTS

Table 2 shows the results secured with various N compounds on Yolo fine sand. The percolating solutions contained 30 milligram-atoms of nitrogen for each column of three pots. Milo was seeded in the dry soil before percolation. Many of these solutions were toxic to the first crop, as shown in Table 2, by the description of the growth after 8 days. In some cases the place of maximum retention coincided with the location of the seed. For the second planting the soil was

TABLE 2.—*Retention of the nitrogen of various percolating solutions by Yolo fine sand in a column of 4-inch pots as shown by the subsequent yields of milo, each yield figure being the average of three cultures*

Pot No.*	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams	1st planting, 8-day growth†	2nd planting, 32-day growth: Green weight, grams	2nd planting, 32-day growth: Dry weight, grams
		NH_4OH			$(NH_4)_2SO_4$			Gelatin	
1, top	O	43.4	6.04	SS	48.7	6.41	G	36.0	6.02
2, middle	G	2.0	0.42	G	1.5	0.32	G	1.6	.37
3, bottom	G	1.7	0.38	G	1.2	0.30	G	1.4	.31
Control		20.3	3.34		26.6	4.12		14.0	2.49
		$NaNO_3$			$NaNO_2$			Distilled water	
1, top	S	14.7	2.53	O	14.3	2.61	G	1.6	0.35
2, middle	G	24.4	4.14	O	18.5	3.25	G	1.6	0.35
3, bottom	G	21.7	3.74	O	19.7	3.45	G	1.7	0.38
Control		19.2	3.60		15.4	2.68		1.7	0.36

*Order of pots in the column during percolation. Control received 1/3 the volume of the same solution as added to the top of the percolating column.

†For 8 day growth of 1st planting, G = good, SS = slightly stunted, S = stunted, and O = no growth.

inverted in each pot and replanted Table 2 likewise gives the resulting yields after 32 days

The distilled water shows a tendency for some nutrient element (probably N as nitrate) to be leached down to the bottom pot. Both plantings show that the nitrogen of NH_4OH is retained by the soil in the top pot; in the first planting by the toxic condition and in the second by the increased growth. The retention of the NH_4 ion of the ammonium sulfate is likewise shown in the yields from the top pot. The nitrogen of the protein, gelatin, is retained in the top pot. The mechanism responsible is not fully evident. Gelatin considered as a colloid dispersed in water would, however, be filtered out of suspension by the soil. The NO_3 ions are not retained but apparently enough Na ions are retained by this light soil to bring about a condition less than optimum in the top pot

With $NaNO_2$ the uniformly toxic condition in the first planting and the rather uniformly good growth of the second show that the NO_2 ions are not retained by the soil. In the intervening 8 days between the two plantings, the nitrite would have time to change more or less completely to the corresponding nitrate.

Tests for the retention of the various elements have been made with various compounds and with different soils deficient in the elements in question during the last year and a half. The more interesting of these are reported in Table 3. The Yolo silt loam retains the NH_4 ions of NH_4NO_3 while the NO_3 ions are not retained

TABLE 3 *Retention of the nitrogen, phosphorus or sulfur of percolating solutions by various soils as shown by the growth of milo* *

Soil	Yolo silt loam		Aiken loam		Huer Huero sandy loam	
Percolating solution	H_2O	NH_4NO_3	H_2O	Na_2HPO_4	H_2O	Na_2SO_4
Order of pots in column:						
1, top	0 22	1 47	0 84	3 61	0.31	3.22
2, middle	0 19	0 83	0 81	0 77	0 27	2.62
3, bottom	0.17	0.88	0.89	0 76	0 60	3.28

*Yields of dry matter in grams per pot, average of triplicate cultures

Nearly every annual crop markedly responds to phosphate applications on Aiken loam. In the case reported in Table 3 the percolating solution contained 1.5 milligram-atoms of P for the column of three pots. In the early stages of growth a total of 9 milligram-atoms of nitrogen as $Ca(NO_3)_2$ and urea was added to each pot in this test as this soil is also N-deficient

The Huer Huero sandy loam, a S-deficient soil, shows no or incomplete retention of the sulfate ion. It is interesting to note that with the distilled water percolated through this soil the bottom pot of this column gave the highest yield, indicating that some S-containing substance had been carried down, probably traces of sulfate leached down. In this case a total of 8 milligram-atoms of N as urea was added

to each pot in the series after growth had started. The sulfate was added at the rate of 1.5 milligram-atoms of S per column.

These results are inconclusive in determining whether the sulfate ion might have been slightly retained by this soil as insufficient N was added to make S the limiting element in the Na_2SO_4 column.

SUMMARY

1. A method is described (Fig. 1) whereby the retention or non-retention of nutrient ions or compounds from percolating solutions by the soil may be shown by plant response. The illustrative material so produced has been a material aid in the presentation of the subjects of ionic exchange and the interaction between fertilizers and soils to students and farmers.

2. The retention of ammonium ions from various ammonium compounds and of phosphate ions demonstrated by plant growth are in agreement with current analytical data as is the non-retention of nitrates, nitrites, and sulfates. Gelatin as a colloid is probably filtered out of the percolating solution by the soil.

3. The method shows promise as a research tool, useful in extending our knowledge of the interaction of various ions and compounds with soils.

INHERITANCE OF RESISTANCE TO LEAF RUST IN COMMON WHEAT[1]

William Eugenius Adams[2]

THIS is a study of the inheritance of leaf rust of wheat, *Puccinia triticina*, Erikss., in crosses between Hope, a resistant variety, with Leap's Prolific, Fulcaster, and Purplestraw, the three leading varieties in North Carolina.

It has long been known that leaf rust of wheat is in many seasons a factor of considerable importance in the production of wheat, especially in the soft red winter wheat areas and particularly in the southeastern states.

Apparently very little work has been done on varieties of wheat adapted to North Carolina. Mains, Leighty, and Johnston[3] made an intensive study of western wheat varieties and drew the following conclusions: In a resistant Kanred cross with several susceptible varieties Kanred resistance may depend upon several factors. In crosses with resistant Malakoff and susceptible varieties in the seedling stage showed Malakoff resistance dependent upon a main dominant genetic factor. In the F_2 there were 3 resistant. 1 susceptible. In other crosses with susceptible Malakoff and Webster a 1:2:1 ratio occurred and resistance appeared to be dependent upon a single main factor difference. In a resistant Fulcaster crossed with susceptible Kanred to physiologic form 9, resistance was dependent upon a single main factor difference. In a Malakoff × C. I. 3778 and Norka × C. I. 3756, the 9:3:3:1 ratio indicated the resistance of each parent dependent upon a single independently inherited factor.

DESCRIPTION OF MATERIAL

The materials used in this study were Leap's Prolific, Fulcaster, and Purplestraw, the three leading soft red winter wheat varieties in North Carolina, all well adapted to the conditions in the state, but not very resistant to leaf rust. Hope,[4] the resistant parent, is a hard red spring wheat of no commercial importance. It has, however, been found valuable as a resistant parent in crosses.

The seed of Hope were furnished by Dr. R. W. Caldwell and J. Allen Clark, Bureau of Plant Industry, U. S. Dept. of Agriculture. The seed for the susceptible parents, Leap's Prolific, Fulcaster, and Purplestraw, were obtained from the Piedmont Branch Station, Statesville, North Carolina.

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[1]Presented as a thesis to the Department of Agronomy of the North Carolina State College of Agriculture and Engineering of the University of North Carolina in partial fulfillment of the requirements for the degree of master of science. Received for publication October 15, 1938.

[2]Formerly Reserach Assistant in Agronomy at North Carolina Agricultural Experiment Station; now Junior Agronomist, Soil Conservation Service, U. S. D. A., Franklinton, North Carolina. Acknowledgment is due Dr. J. B. Cotner for supplying the material for the study and for his advice and directions of the work.

[3]Mains, E. B., Leighty, C. E., and Johnston, C. O. Inheritance of resistance to leaf rust, *P. triticina*, in crosses of common wheat, *T. vulgare*. Jour. Agr. Res., 33:931. 1926.

[4]Clark, J. Allen, Martin, John M., and Ball, Carleton, R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.

Clark, J. Allen. Correspondence, February 25, 1935.

METHOD OF PROCEDURE

Crosses of Hope with Leap's Prolific, Fulcaster, and Purplestraw were made as follows: (1) Leap × Hope, (2) Hope × Leap's Prolific, (3) Hope × Fulcaster, and (4) Purplestraw × Hope.

The parents and first generation hybrids were planted in the field at Raleigh, North Carolina, October, 1932. The parents were also planted again with the F_2 and F_3 material in October, 1933 and 1934, respectively. The F_2 and F_3 material were grown at both Raleigh and Statesville, North Carolina.

In the field nurseries at Raleigh and Statesville the infection of the parents and hybrids resulted from the rust naturally occurring in these localities. In most instances, leaf rust was so abundant that susceptible varieties were heavily infected and a very good test of reaction to the rust was obtained. Under such conditions it was impossible to control the physiologic forms of rust by which the hybrids were infected.

In taking notes upon hybrids in the field nurseries, infection was determined, according to the scale used by the Office of Cereal Investigations, U. S. Dept. of Agriculture[5] by which it is estimated in percentages the number of uredenia actually formed compared with the number possible. Notes were taken when infection had reached its maximum development. The plants were classified according to the types of infection which developed. Seven different classes of rust infection were recognized, based upon the degree of the infection.

RESULTS OBTAINED

Table 1 gives the comparative susceptibility and resistance of parents and F_2 plants. In 1934 and 1935, 76 and 87% respectively, of the Hope plants showed less than 1% of rust infection. No plants

TABLE 1 —*Reaction of parent varieties and F_2 plants grown at Statesville in 1934*

Variety or cross	Infection percentage						
	0	Trace (0 1–0 9)	1 4	5 25	25 50	50 75	75 100
Hope	8	43	12	4	—	-	—
Leap's Prolific			—		16	48	64
Fulcaster		-	4	16	23	3	--
Purplestraw		—		-	12	25	15
Hope × Leap's Prolific F	-	9	18	31	12	1	-
Leap's Prolific × Hope F		-	2	19	22	19	6
Purplestraw × Hope F		24	34	43	10	-	—
Hope × Fulcaster F_2		28	85	46	2	-	—

showed more than 25% infection. Leap's Prolific, apparently highly susceptible, showed all plants above 25% infection, with 87% of those grown in 1937 and 40% of those grown in 1935 above 75% infection. Purplestraw was all above 25% infection, with 50% of the plants grown each year in the 50 to 75% class. Fulcaster, apparently less susceptible than Leap's Prolific and Purplestraw, showed a few plants in the 1 to 4% class, 50% in the 25 to 50% class, and no plants showing more than 75% infection in 1934. In 1935, 50% of the plants were in the 50 to 75% class.

[5]See footnote 3

The F_1 showed very little infection. This was apparently due to either a small amount of inoculum or unfavorable weather conditions for the development of spores, or both.

The Hope×Leap's Prolific F_2 (Figs. 1 and 2) gave immune, intermediate, and susceptible plants with 81% below 25% infection, and nine plants less than 1% infection. In the reciprocal F_2 cross, Leap× Hope, did not show quite as much resistance with 63% below 50% infection and 31% in the 25 to 50% class. Two plants were in the 1 to 4% class. The Purplestraw×Hope F_2 (Fig. 3) showed no plants

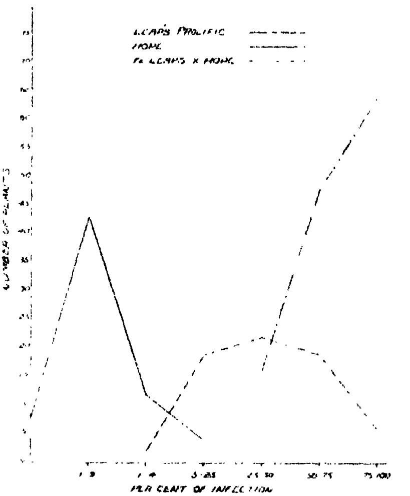

FIG. 1.

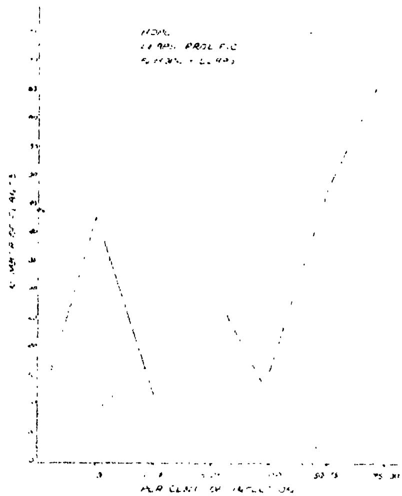

FIG. 2.

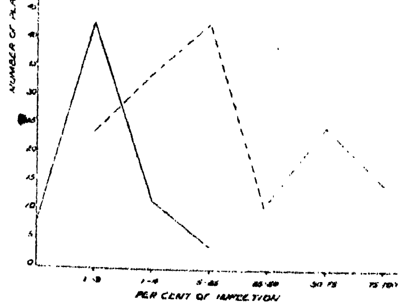

FIG. 3.

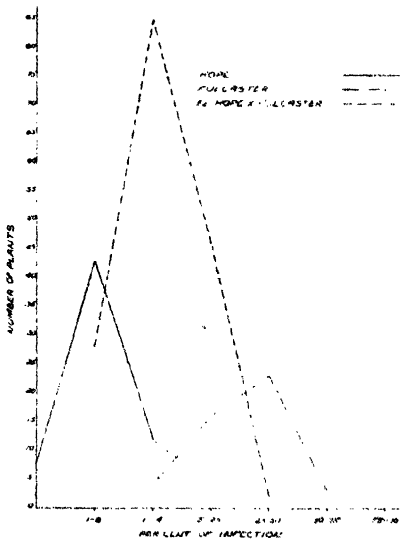

FIG. 4.

above 50% infection, with 91% below 25% and 27% under 5% infection. The Hope×Fulcaster F_2 (Fig. 4) showed more resistance than any of the crosses. There were 70% of the plants less than 4% and all plants less than 50% infection.

The Purplestraw×Hope F_3 (Table 2), showed four rows under 1%, six rows intermediate, and three rows rather highly infected.

TABLE 2.—*Purplestraw×Hope (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
1080	11	4	–	-	–	–	–
1081	8	6	..	–	–	–	–
1082	–	1	3	6	4	1	–
1085	–	3	2	3	5	1	–
1103	12	1		–	-	–	–
1104	13	–	–	..	–	..	–
1107	–	..	–	–	8	3	4
1154	1	3	3	2	4	2	1
1155	3	2	3	1	2	3	1
1158	1	2	3	1	2	1	–
1159	1	1	2	2	3	1	–
1160	5	6	3	–	–	–	–
1161	4	7	5	–	–	–	–
1164	–	–	–	–	5	6	3
1165	–	–	–	–	3	8	4
1172	8	6	1	–	–	–	-
1173	6	5	2	–	–	–	–

*Rows above 1,150 grown at Raleigh; others grown at Statesville.

The Hope×Fulcaster F_3 (Table 3), showed three rows under 1%, five intermediate rows, and three rows above 50% infected.

TABLE 3.—*Hope×Fulcaster (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1–4	5–25	25–50	50–75	75–100
2619			2	3	2	3	–
2630	2	3	1		–	·	–
2631	2	6	·	–	..	..	–
2632	-	3	4	3	2	2	–
2901	7	9		·	..	–	–
2902	7	6	-	-	..	–	–
2904	2	4	6	4	1	1	–
2905	1	6	5	3	1	1	–
2906	1	7	4	3	2	1	1
2913	·		·	-	2	5	6
2914	–	–	-	–	4	3	1
2915	–	-	-	–	2	3	4

*Rows in 2,600 group grown at Statesville; rows in 2,900 group grown at Raleigh.

In the Hope×Leap's Prolific F_3 (Table 5) there were six resistant rows with the majority of the plants with no infection, five intermedi-

ate rows, and four rows showing greater than 50% infection. The reciprocal Leap's Prolific×Hope F_3 (Table 4), indicated similar results, with five rows under 1% infection, five intermediate rows, and three rows with all plants above 50% infection.

TABLE 4.—*Leap's Prolific×Hope (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1 4	5–25	25–50	50–75	75–100
1541	-		-		4	7	1
1542	-			-	-	9	6
1543	9	7	-		-	-	-
1544	7	8	-		-	-	-
1545	2	3	3	4	2	2	1
1546	-	1	3	8	1	2	1
1549	-	2	7	4	3	2	-
1550	8	7	-	-	-	-	-
2047	-	-	-		-	9	6
2048	-		-	-		10	4
2084	-	2	5	6	3	1	1
2085	1	1	3	5	3	1	2
2086	6	7		-	-	-	-
2087	8	6	-	-	-	-	-

*Rows in 1,500 group grown at Statesville; rows in 2,000 group grown at Raleigh.

TABLE 5.—*Hope×Leap's Prolific (F_3), 1935.*

Row No.*	Infection percentage						
	0	Trace 0.1–0.9	1 4	5–25	25–50	50–75	75–100
1727	11	2	-	-	-	-	-
1728	7	6	-	-	-	-	-
1730	-	-	-	-	-	8	5
1731	-	2	3	6	7	2	-
1732	-	-	-	-	-	7	8
2428	7	4	-	-	-	-	-
2430	1	2	2	3	2	2	1
2433	1	2	1	3	6	3	1
2435	1	1	2	2	3	4	1
2436	-	1	5	3	5	3	1
2437	6	4	-	-	-	-	-
2438	7	3	-	-	-	-	-
2439	4	5	-	-	-	-	-
2440	5	3	2	-	-	-	-
2523	-	-	-	-	-	5	4
2526	-	-	-	-	1	3	4
2581	-	-	-	-	-	6	5

*Rows in 1,700 group grown at Statesville; rows in 2,400 and 2,500 groups grown at Raleigh.

In these trials the results are complicated by varying conditions of soil, climate, time of maturity, and mixtures of physiologic forms and an accurate determination of the facts of inheritance is difficult. The results would seem to indicate that resistance to leaf rust of wheat is

inherited, since the F_2 showed plants which were resistant, intermediate, and susceptible. The F_3 gave highly resistant rows, intermediate rows, and highly susceptible rows. In the F_3, families were obtained in each cross which showed less than 5% infection.

SUMMARY

Hope, a variety resistant to leaf rust of wheat, *Puccinia triticina*, Erikss., was crossed with Leap's Prolific, Fulcaster, and Purplestraw, susceptible varieties, with the following results:

1. The F_1 showed very little infection, apparently due to a small amount of inoculum or unfavorable weather conditions for this development.
2. The F_2 showed plants which were resistant, intermediate, and susceptible.
3. The Hope×Leap's Prolific F_2 showed 81% of the plants below 25% infection. The reciprocal cross, Leap's Prolific×Hope F_2, gave similar results.
4. The Purplestraw×Hope F_2 showed 91% of the plants below 25% infection.
5. The Hope×Fulcaster F_2, showing greater resistance than any of the crosses, gave 70% of the plants below 4% infection.
6. The F_3 gave rows which were highly resistant, intermediate rows, and also highly susceptible rows. F_3 families were obtained in each cross which showed less than 5% infection.

AN UNUSUAL ALKALI SOIL[1]

W. P. KELLEY AND S. M. BROWN[2]

PRELIMINARY tests made several years ago on an alkali soil sent to us by Professor W. W. Johnston of the Oregon Agricultural College, gave results which suggested that this soil probably contains a significant amount of some soluble alkaline substance other than carbonate and bicarbonate. For instance, it was found that the amount of standard acid required to titrate a water extract of this soil with phenolphthalein as indicator was considerably more than half that required with methyl orange.

As is well known, two steps are involved in the neutralization of normal carbonate. First, its conversion into bicarbonate, and second, the conversion of bicarbonate into CO_2 and H_2O. These reactions are illustrated by the following equations:

$$\text{(a)}\quad 2Na_2CO_3 + H_2SO_4 \rightleftharpoons 2NaHCO_3 + Na_2SO_4$$

$$\text{(b)}\quad 2NaHCO_3 + H_2SO_4 \rightleftharpoons 2CO_2 + 2H_2O + Na_2SO_4$$

The completion of reaction (a) corresponds to the phenolphthalein end point, whereas that of reaction (b) represents the end point with methyl orange, equal quantities of acid being neutralized in both steps of the reaction. Since reactions (a) and (b) are both included in the methyl orange titration, the amount of acid required with this indicator is just twice that required with phenolphthalein. We found, however, that in the titration of a water extract of this soil, the latter was considerably more than one-half that of the former. Ordinarily, the phenolphthalein titration of soil extracts requires considerably less than half as much acid as the methyl orange titration, which, of course, indicates that these extracts contain bicarbonate.

Accordingly, a more critical study of this soil has recently been made. The soil in question was taken from the upper 4 inches of virgin alkali land adjacent to the area on which the Oregon Agricultural College has conducted alkali reclamation experiments for many years (1, 5).[3] According to a statement sent to us by Professor Johnston, this soil was quite similar to that on which the reclamation experiments were located. In 1934, Wursten and Powers (5) reported that the virgin soil near these experiments contains considerable normal carbonate but no bicarbonate.

A water extract was prepared by shaking to approximate equilibrium 400 grams of the air-dried soil with 2,000 cc distilled water, then filtering through a Chamberland-Pasteur filter. Again it was found that the phenolphthalein titration required considerably more than half as much acid as the methyl orange titration. Accordingly, complete chemical analysis of the extract was made including Cl, SO_4, NO_3, PO_4, carbonate CO_2, SiO_2, Ca, Mg, K, Na, and pH.

[1]Contribution from the Citrus Experiment Station, University of California, Riverside, Calif. Received for publication October 17, 1938.

[2]Agricultural Chemist and Assistant Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 43.

Table 1 shows the analytical results expressed on the basis of 1 liter of the extract. It was found that the solution contained an unusually large amount of SiO_2 in addition to substantial amounts of CO_3, Cl, SO_4, and small amounts of NO_3 and PO_4. The principal base was Na. In view of the fact that the solution was brown-colored and contained a complex series of constituents, an electrometric titration was made using the glass electrode. The data, when plotted, showed two deflections in the curve, the first at about pH 8.5 and second at about pH 5.5, which corresponded roughly to the phenolphthalein and methyl orange end points, respectively. The amounts of acid required to produce these changes in pH were also approximately the same as in the colorimetric titrations.

TABLE 1.—*Analysis of 1 to 5 water extract of Vale, Oregon, alkali soil.*

Acid titration		Milligrams per liter										
Phenolphthalein (cc N/10 acid per 1,000 cc)	Methyl orange (cc N/10 acid per 1,000 cc)	Cl	SO_4	NO_3	PO_4	SiO_2	Carbonate CO_2	Ca	Mg	K	Na	pH
133.5	226.7	291.4	874.6	4.7	20.6	374.9	255	4	Trace	144.3	1231.5	10.75

Since the water extract was strongly alkaline (pH 10.75) and also contained substantial amounts of dissolved SiO_2, it is reasonable to conclude that sodium silicate was present in the solution. In view of the fact that, at the concentration and pH of the original solution practically all carbonate must have existed in the form of normal carbonate, it is concluded that this soil extract contained Na_2CO_3, Na_2SiO_3, NaCl, Na_2SO_4, and smaller amounts of $NaNO_3$ and Na_2HPO_4.

The several ions expressed as milliequivalents per liter ar e shown in Table 2. In making the calculations it was assumed that all the SiO_2 and carbonate CO_2 occurred in the solution as SiO_3 and CO_3 ions, respectively As thus calculated, the total cations exceeded the total anions by 6.4 milliequivalents per liter. This suggests that a part of the sodium was present either in organic combination, which seems quite probable in view of the dark brown color of the solution, or that NaOH was present in significant amounts. It should be recalled that so-called sodium silicate commonly contains a greater amount of Na than is required by the formula Na_2SiO_3.

TABLE 2.—*Water-soluble ions expressed as milliequivalents per liter.*

Cl	SO_4	CO_3	SiO_3	NO_3	HPO_4	Total anions	Ca	Mg	K	Na	Total cations
8.2	18.2	11.6	12.5	0.08	0.4	50.98	0.2	Trace	3.7	53.5	57.4

The preceding discussion has dealt with a 1 to 5 water extract of this soil. In view of the data recently published by McGeorge (3, 4) and Keaton (2), it is probable that the pH of this soil under field moisture conditions is substantially lower than that of a 1 to 5 water extract. If so, the equilibrium between CO_3 and HCO_3 would be shifted in the direction of increased HCO_3. Therefore, in the open field, it is possible that this soil contains both HCO_3 and CO_3 in significant amounts. At about pH 10.4 and with the total amount of CO_2 found, there should be approximately two equivalents of CO_3 to one equivalent of HCO_3, and as the pH is lowered still further, HCO_3 will increase at the expense of CO_3 until at about pH 8.5 practically all CO_3 will be converted into HCO_3.

The exceptional feature of this soil is that it contains a substantial amount of sodium silicate in addition to soluble carbonate and the other salts common to alkali soils Although it is common to find soluble SiO_2 in black alkali soils, the amount is usually small. This Oregon soil, however, contains relatively much soluble silica. Therefore, the geological and pedological history of this soil is a matter of some interest.

LITERATURE CITED

1. JOHNSTON, W. W., and POWERS, W. L. A progress report of alkali land reclamation investigations in eastern Oregon. Ore. Agr. Exp. Sta. Bul. 210. 1924.
2. KEATON, C. M. A theory explaining the relation of soil-water ratios to pH values. Soil Science, 46:259–265. 1938.
3. McGEORGE, W. T. Report on hydrogen-ion concentration of alkali soils. Jour. Assoc. Off. Agr. Chem., 20:220-221. 1937.
4. ————. The determination of soil reaction under field conditions by means of the spear-type glass electrode. Jour. Amer. Soc. Agron., 29:841–844. 1937.
5. WURSTEN, J. L., and POWERS, W. L. Reclamation of virgin black alkali soils. Jour. Amer. Soc. Agron., 26:752–762. 1934.

LEACHING STUDIES WITH VARIOUS SOURCES OF NITROGEN[1]

NELS BENSON AND R. M. BARNETTE[2]

BECAUSE of the open texture and ready penetration of water into many Florida soils, one of the most difficult problems in their management is the serious losses to which their soluble plant food components are exposed by direct leaching. This is especially true of nitrogen and accounts largely for the constant attention required to maintain in such soils an adequate balance of this element for nonleguminous plants.

If a soluble form of nitrogen could be found, therefore, that is consistently more stable in such soils and not so easily leached, obviously it would find a wide application under Florida conditions. The principal purpose of this paper is to present the results of a study of the stability against leaching of nitrogen in a number of fertilizer materials.

REVIEW OF LITERATURE

The loss of nitrogen from soils through leaching has been reported by many investigators (2, 4, 5, 6, 7, 12, and others).[3] Nitrate nitrogen is the main constituent lost, although other forms may leach to a lesser extent.

In some of these investigations fallow lysimeters have been treated with nitrogenous fertilizers and the leachings studied through definite periods varying from a few months to several years. These studies have shown almost complete recovery of nitrogen from applications of the nitrate form, most of which leached shortly following its application. Urea has been transformed to nitrate and efficiently leached in that form. Sulfate of ammonia has been nitrified to a slightly lesser extent than urea as indicated by a lower leaching of nitrate nitrogen. The insoluble organic fertilizers, on the other hand, have not been recovered very efficiently in the leachates.

Ammonium nitrogen has been reported to wash from light-textured soils when leaching took place shortly after the application of ammonium sulfate. The extent of the leaching has been found to vary directly with the base exchange capacity of the soil.

Parker (8) rated the retention of nitrogen sources by the soil as follows: Sodium nitrate, readily leached; urea, ammonium sulfate, and insoluble organics, leached with difficulty.

A study was undertaken to determine the relative leachability of different forms of nitrogen—nitrate, ammonium, nitrite, and urea—at various intervals following the application of nitrogenous materials to Norfolk sand. The leaching of nitrogen from this soil was further compared with other soils of different colloid content and properties.

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[2]Research Fellow, E. I. Du Pont de Nemours and Co. Inc., and Chemist, Department of Chemistry and Soils, University of Florida, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 53.

SOILS USED IN THE WORK

In selecting soils for the study it was desired that a certain variation in texture and colloid content be involved; also that their distribution and economic importance be considered. Accordingly the following types were selected:

1. A Norfolk sand was obtained from a cultivated field at Gainesville, Florida. It is a well-drained soil having the following profile characteristics: Six inches of dark yellowish gray surface sand underlain by pale yellow sand.

2. A Bladen fine sand was obtained from a cultivated field near Hastings, Florida. The surface 8 inches consists of dark gray fine sand below which is a lighter gray fine sand to a depth of 30 inches, which changes abruptly to a heavy yellow sand and clay mixture mottled with gray, blue, and white. It is a poorly drained soil.

3. A Fellowship fine sandy loam was obtained from a virgin a·ea west of Gainesville The surface 8 inches is a dark yellowish brown fine sand grading into a lighter brownish yellow loamy fine sand with a slight crumb structure, becoming heavier at increasing depths to 20 inches where it changes rather abruptly into a very heavy yellow cl·· overlying limestone. Fragments of limestone and chert lie on top (the soil and are distributed throughout the profile. This soil type, a though high and undulating, is considered to be poorly drained l, cause of the impervious clay a short distance below the surface.

4. A Norfolk fine sandy loam was obtained from a virgin area Graceville, Florida. The upper 6 inches is dark gray loamy fine s· grading into yellow fine sandy loam, extending to a depth of 48 inc where it changes to a mottled red, yellow, and white fine sandy c

PARTIAL MECHANICAL AND CHEMICAL ANALYSES OF SOI

Results of the mechanical analysis and the determination of base exchange capacity, replaceable calcium, and percentage nitr(for the surface and subsoil samples of these soils are given in Tab

The Norfolk sand contained the least fine clay, the Norfolk sandy loam the most The Fellowship fine sandy loam had the higl base exchange capacity and also the most replaceable calcium. though the Bladen fine sand had a lower base exchange capacit\ the surface soil than the Norfolk sand, it had a much higher value the subsoil.

The mechanical analyses were made by the method of Bouyou((3). The base exchange capacity was determined by leaching 50 gra of soil with 1 liter of neutral normal ammonium acetate accor·ing the method of Schollenberger and Dreibelbis (10). Calcium w determined in the filtrate[4] and nitrogen on the original soil samples l the Gunning-Hibbard (1) method.

EXPERIMENTAL PROCEDURE

Glazed coffee urn type pots of 3-gallon capacity were used as small lysim The hole in the bottom of the pot was provided with a rubber stopper th

[4]Unpublished methods of M. Peech.

TABLE 1.—*Some physical and chemical characteristics of soils used in leaching studies.*

Soil	Depth, inches	Fine gravel and sands, 2.0–0.05 mm, %	Silt, 0.05–0.005 mm, %	Clay, <0.005 mm, %	Fine clay, <0.002 mm, %	Nitrogen, %	Milliequivalents per 100 grams of soil	
							Base exchange capacity	Replaceable calcium
Norfolk sand	0–6	96.2	2.3	1.5	0.8	0.035	2.99	0.95
	6–24	95.8	2.7	1.6	1.3	0.011	1.18	0.50
Bladen fine sand	0–8	86.8	7.8	5.4	4.4	0.065	2.47	1.55
	8–30	90.2	4.8	5.0	3.0	0.026	2.68	0.95
Fellowship fine sandy loam	0–8	88.8	7.2	4.0	3.4	0.036	5.12	2.65
	8–20	85.0	7.4	7.7	7.0	0.019	3.85	3.55
Norfolk fine sandy loam	0–6	74.1	17.3	8.6	7.4	0.038	3.91	0.70
	6–10	71.7	14.9	13.4	11.1	0.025	3.29	0.60
	10–20	67.6	13.1	19.3	16.6	0.020	3.43	0.50

ich a short piece of glass tubing was inserted for drainage. A cover glass with convex surface turned upward was used to cover the hole on the inside of the and served to prevent loss of sand during leaching.

afficient quantities of topsoil and subsoil were air dried in the greenhouse and ned through a 2-mm sieve. The pots were tared with carefully washed white ing sand which aided in maintaining the appropriate water content of the res.

r comparing the leaching of nitrogen at various intervals after the applica- f different sources to Norfolk sand, the following procedure was employed: unds of the subsoil, equivalent to a depth of 6¼ inches, were placed on building sand in the bottom of the vessel. Distilled water was added to subsoil to the desired moisture content (13%). After a short time, 10 f the topsoil in which the nitrogenous materials had been intimately re added, making a depth of 3 inches of topsoil. Distilled water was then o bring the topsoil to the desired percentage of moisture (11%). The cul- re allowed to stand until time of leaching with additions of water about week to replace that lost through evaporation.

nitrogenous materials were applied according to the surface area exposed rate of 2,000 pounds per acre of a mixture containing 4% nitrogen. This amounted to 408 milligrams of nitrogen per culture. Total nitrogen determi- ons were made on all the fertilizer materials previous to their use. Quantities he materials equivalent to 408 milligrams of nitrogen were weighed and mixed the topsoil of each culture, except calcium and ammonium nitrates which pplied in solution because of their deliquescent properties. Ammonium nate was also added as a solution because of its unstable nature. All cul- re set up in triplicate and kept in a greenhouse where the average tem- was approximately 21°C.

dying the effect of time of standing or incubation on the amount of st, representative groups of cultures were leached after 1-, 4-, 10-, and

21-day periods with 5 liters of distilled water, equivalent to approximately 4½ inches of rainfall for the surface area. The water was applied in 250-milliliter aliquots to facilitate slow continuous leaching. This quantity of water effected a leaching of 3 to 3½ liters, the equivalent of about 3 inches of water. Three hours were required to leach the 33 cultures of each series.

The chemical analyses were made on the same day that the leachings were collected. The H-ion concentrations were determined on original samples of the leachates by using the glass electrode. Where necessary the leachates were clarified with two drops of a 5% aluminum sulfate solution per 100 milliliters. The different nitrogen compounds were determined colorimetrically by the phenoldisulfonic acid method (11) for nitrates and the dimethylaphanaphthylamine method (11) for nitrites. Ammonia was determined by direct nesslerization with the addition of 1 milliliter of a gum arabic solution for the stabilization of the colloidal precipitate (11). Urea was determined by the difference between the digestion with urease and subsequent distillation and nesslerization of the distillate and the ammonia determination.

In studying the leaching of nitrogen from different soils, after standing for four days, the same procedure was employed as in those involving different periods of incubation. The amounts of topsoil and subsoil used were calculated in proportion to the depths of the profile and the depth of the pots. The amounts of topsoil and subsoils used were as follows: Norfolk sand, 0–6 inches, 10 pounds, 6–24 inches, 20 pounds; Fellowship fine sandy loam, 0–8 inches, 12 pounds, 9–20 inches, 18 pounds; Bladen fine sand, 0–8 inches, 8 pounds, 8–30 inches, 22 pounds; and Norfolk fine sandy loam, 0–6 inches, 9 pounds, 6–10 inches, 6 pounds, 10–20 inches, 15 pounds.

In this second series, nitrogen forms studied were limited to the following sources: Sodium nitrate, ammonium sulfate, urea, and castor pomace. A nitrogen equivalent of 408 milligrams of the materials was mixed with the surface soil and then added to the pot. The topsoil and the subsoil of the cultures were adjusted to predetermined optimum moisture contents with distilled water as outlined above. For obvious reasons the moisture content of the subsoil was adjusted before the surface layers were added.

The cultures of this series were leached after four days with sufficient water to effect a percolate of 3 to 3½ liters, equivalent to approximately 3 inches of water for the surface area. The required amount of water was 5 liters for Norfolk sand, 5½ for Bladen fine sand, 6 for Fellowship fine sandy loam, and 6½ for Norfolk fine sandy loam.

Samples of the surface soil for pH determinations were taken with a cork borer of ⅜ inch diameter just prior to leaching the cultures. Four borings were mixed for each culture. The holes were refilled with dry soil of the same type before leaching. Samples were taken again after leaching in the same manner, avoiding the locations of the previous borings. The determinations were made with the use of a glass electrode after preparing a 1:2 soil-distilled water suspension.

EXPERIMENTAL RESULTS

EFFECT OF TIME OF STANDING OR INCUBATION ON LEACHING OF NITROGEN FROM NORFOLK SAND WHEN APPLIED IN VARIOUS FORMS

The percentage of the total nitrogen applied that was leached from Norfolk sand as nitrates, ammonium ions, and urea after 1, 4, 10,

and 21 days of incubation is given in Table 2. The percentage of nitrogen leached was calculated by subtracting the amount of nitrogen leached from the untreated cultures from the amount leached from the treated cultures and dividing the result by the amount of nitrogen applied.

All nitrate nitrogen was leached after each incubation period whether applied as sodium, calcium, or ammonium nitrate.

Urea was present as such in the leachings from the 24-hour and 4-day incubation periods. Thirty-five per cent of the amount of urea nitrogen applied was present in the leachate from the 24-hour incubation period and 16% from the 4-day period. Tests made on the leachates from the 10- and 21-day periods failed to show the presence of urea. This is probably due to the fact that urea hydrolyzes to ammonium carbonate very quickly in the soil by the action of microorganisms. Therefore, within a few days after application, it should show a reaction similar to that of ammonium carbonate. Very little ammonium nitrogen was leached from the urea cultures until nitrates were formed.

The leachates from the cultures treated with the insoluble organic materials, fish meal, castor pomace, and tankage, contained very little more nitrogen than those from the untreated cultures. A slightly greater quantity of nitrate nitrogen was formed in the treated cultures as shown by the leaching of 0.7 to 3.0% of the nitrogen applied during the 10- and 21-day periods.

The quantities of nitrites leached are shown in Table 3. Nitrite nitrogen did not leach to a great extent. The ammonium carbonate treatment incubated for 10 days gave 4.1 milligrams of nitrite nitrogen per culture. The urea-treated culture gave 1.6 milligrams for the same interval. In most cases there were insufficient quantities to determine. Nitrites have been reported present in some Florida soils in sufficient quantities to cause malnutrition in certain crops (9).

The pH values of the leachates from each incubation period are given in Table 4. The addition of sodium nitrate, calcium nitrate, ammonium nitrate, ammonium phosphate, and ammonium sulfate materially lowered the reaction of the leachates. Ammonium carbonate and urea lowered the pH of the leachate to a lesser extent. The insoluble organic materials had but very slight influence on the pH of the leachate and of these materials fish meal produced the lowest pH values.

COMPARATIVE LEACHINGS OF NITROGEN APPLIED IN VARIOUS FORMS FROM DIFFERENT SOILS AFTER FOUR DAYS OF INCUBATION

To compare the leachability of different nitrogen sources from different soils, four distinct soil types were used and the nitrogen sources were limited to four different forms. On the basis of the results found in the time study reported above, only one incubation period, 4 days, was used.

The percentage of the nitrogen applied which was leached from the different soils is given in Table 5. The pH values of the soils

TABLE 2.—*The percentage of nitrogen leached at different intervals from Norfolk sand following the application of various nitrogen fertilizers.*

	Leached as nitrate				Leached as ammonium				Leached as urea				Total nitrogen leached*			
	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days	1 day	4 days	10 days	21 days
Sodium nitrate	105.1	99.0	101.7	96.7	0.4	1.0	1.3	1.3	—	—	—	—	105.5	100.0	103.0	98.0
Calcium nitrate	94.1	91.4	100.4	91.3	3.0	3.8	4.9	4.8	—	—	—	—	97.1	95.2	105.3	96.1
Ammonium nitrate	53.2	52.0	58.0	55.0	17.3	15.4	18.1	18.6	—	—	—	—	70.5	67.4	76.1	73.6
Ammonium phosphate	0.3	2.7	1.2	2.3	10.6	14.0	8.3	2.6	—	—	—	—	10.9	16.7	9.5	4.9
Ammonium carbonate	—	—	3.4	8.8	3.1	—	0.6	6.0	—	—	—	—	3.1	—	4.0	14.8
Ammonium sulfate	—	0.9	2.0	2.0	32.0	41.9	33.1	39.7	—	—	—	—	32.0	42.8	35.1	41.7
Urea	—	—	2.0	8.1	0.1	0.4	1.8	10.6	35.0	16.0	—	—	35.1	16.4	3.8	18.7
Fish meal	—	—	3.3	2.4	0.2	1.7	2.6	9.7	—	—	—	—	0.2	1.7	5.9	12.1
Castor pomace	—	—	2.0	2.2	0.1	0.1	0.9	5.1	—	—	—	—	0.1	0.1	2.9	7.3
Tankage	0.3	—	0.7	1.5	0.1	0.7	0.7	1.8	—	—	—	—	0.4	0.7	1.4	3.3

*Nitrite nitrogen not included in total nitrogen leached.

TABLE 3.—*Milligrams per culture of nitrogen leached as nitrite from Norfolk sand at different intervals following the application of various nitrogen fertilizers.*

Nitrogenous materials added	Period of incubation			
	1 day	4 days	10 days	21 days
Sodium nitrate	0.07	0.02	—	—
Calcium nitrate	0.03	—	—	—
Ammonium nitrate	0.08	—	—	—
Ammonium phosphate	—	—	—	—
Ammonium carbonate	0.08	0.02	4.10	—
Ammonium sulfate	0.03	—	—	—
Urea	0.06	0.02	1.63	0.26
Fish meal	0.03	0.62	0.12	0.27
Castor pomace	0.18	0.60	0.16	0.31
Tankage	0.04	—	—	—
No treatment	0.04	—	—	—

TABLE 4.—*The pH values of leachates from Norfolk sand from cultures treated with various nitrogenous fertilizers after different periods of incubation.*

Nitrogenous materials added*	pH of leachate			
	1 day	4 days	10 days	21 days
Sodium nitrate	6.12	6.02	5.96	5.99
Calcium nitrate	5.38	5.38	5.40	5.20
Ammonium nitrate	5.97	5.89	5.83	5.86
Ammonium phosphate	6.02	5.78	5.97	6.22
Ammonium carbonate	6.50	6.35	6.04	6.14
Ammonium sulfate	6.08	5.76	5.73	5.97
Urea	6.55	6.27	6.24	6.23
Fish meal	6.67	6.21	5.82	6.39
Castor pomace	6.66	6.30	6.50	6.49
Tankage	6.55	6.50	6.52	6.45
No treatment	6.84	6.57	6.85	6.58

*Materials were added at the rate of 408 mgs of nitrogen per culture.

before and after leaching and the pH values of the leachates are given in Table 6.

The nitrogen applied as sodium nitrate was almost completely recovered in the drainage from Norfolk sand (96.7%), Bladen fine sand (96.3%), and Fellowship fine sandy loam (97.6%). The Norfolk fine sandy loam retained a portion of the nitrate nitrogen, 72.2% being leached.

The leaching of nitrogen in the form of the ammonium radical showed great variation with the different soils treated with ammonium sulfate. The ammonium nitrogen leached from the different soils was as follows: Norfolk sand, 40.3%; Bladen fine sand, 3.1%; Fellowship fine sandy loam, 1.8%; Norfolk fine sandy loam, no increase over the untreated culture.

It has been reported that the leaching of ammonium nitrogen varies directly with the base exchange capacity of the soil (7). The data given here bear out this observation, with the exception of Fellowship fine sandy loam which allowed more ammonia to leach than

TABLE 5.—*The percentage of nitrogen leached after four days of incubation from different soils when treated with various nitrogenous materials.*

Treatment	Nitrate, %	Ammonium, %	Total %
	Norfolk Sand		
Sodium nitrate	96.7	1.2	97.9
Ammonium sulfate	—	40.3	40.3
Urea	1.5	1.1	2.6
Castor pomace	—	0.1	0.1
	Bladen Fine Sand		
Sodium nitrate	96.3	0.5	96.8
Ammonium sulfate	—	3.1	3.1
Urea	—	—	—
Castor pomace	—	—	—
	Fellowship Fine Sandy Loam		
Sodium nitrate	97.6	1.0	98.6
Ammonium sulfate	3.1	1.8	4.9
Urea	1.0	—	1.0
Castor pomace	—	—	—
	Norfolk Fine Sandy Loam		
Sodium nitrate	72.2	0.7	72.9
Ammonium sulfate	0.5	—	0.5
Urea	0.1	—	0.1
Castor pomace	0.4	—	0.4

Norfolk fine sandy loam. This exception is probably due to the crumb structure of the Fellowship fine sandy loam subsoil. Soils saturated or nearly saturated with calcium ions are very difficult to deflocculate. While the Norfolk fine sandy loam became puddled, exposing the colloidal particles to base exchange, the Fellowship fine sandy loam retained its structure. Consequently, a large percentage of the colloidal particles did not enter into the base exchange activities, at least to the same extent as those with better individual exposure provided by their single particle structure.

No urea was found in the leachates from any of the soils. The average temperature of the greenhouse (29° C) at the time of this study was somewhat higher than that for the earlier series. As a matter of fact, it was very near the optimum reported for urea-hydrolyzing bacteria (13).

The ammonium nitrogen leached from the urea treatments was very small. Norfolk fine sandy loam did not yield sufficient amounts to give a test with Nessler's reagent. The Fellowship fine sandy loam, Bladen fine sand, and Norfolk sand allowed 1% or less of nitrogen to leach in this form.

Castor pomace had no significant effect upon the leaching of either nitrate or ammonium nitrogen for this limited period of incubation.

The acidity of the leachate was greater than that of the soil for all treatments of all soils, both before and after leaching. The pH value of the soil was raised by leaching. This decrease in acidity was not significant in the untreated, urea, and castor pomace cultures. The pH

TABLE 6.—*The pH values of soils and leachates from cultures receiving different sources of nitrogen.**

Nitrogenous material added	pH of soil		pH of leachate
	Before leaching	After leaching	
	Norfolk Sand		
Sodium nitrate	5.69	6.31	5.05
Ammonium sulfate	5.46	6.16	4.87
Urea..........	6.52	6.98	5.16
Castor pomace	6.09	6.36	5.19
No treatment	5.63	5.84	5.16
	Bladen Fine Sand		
Sodium nitrate.	4.79	5.91	3.97
Ammonium sulfate	4.78	5.69	3.98
Urea	6.10	6.11	4.58
Castor pomace	5.80	5.74	4.48
No treatment	5.42	5.42	4.47
	Fellowship Fine Sandy Loam		
Sodium nitrate	5.96	6.40	5.40
Ammonium sulfate	5.80	6.33	5.14
Urea	6.34	6.65	5.59
Castor pomace	6.16	6.44	5.62
No treatment	5.96	6.10	5.53
	Norfolk Fine Sandy Loam		
Sodium nitrate	4.87	5.97	4.54
Ammonium sulfate	5.06	5.71	5.61
Urea	6.26	6.06	5.36
Castor pomace	5.72	5.83	5.22
No treatment	5.53	5.61	5.48

*Observations made after an incubation period of four days

value of the soil was not greatly influenced by the addition of the fertilizer except in the cultures treated with urea where this material appreciably decreased the acidity for the period of the experiment.

SUMMARY

An experiment using small, percolation-type lysimeters was conducted to determine the relative leaching of nitrogen in the form of nitrate, nitrite, urea, and ammonia from Norfolk sand after treatment with several nitrogenous materials, including sodium nitrate, calcium nitrate, ammonium nitrate, ammonium phosphate, ammonium carbonate, ammonium sulfate, urea, fish scrap, castor pomace, and tankage. An equivalent of 408 milligrams of nitrogen was applied to 10 pounds of surface soil and placed in the pot on top of 20 pounds of moistened subsoil. The cultures were established and allowed to stand for 1, 4, 10, and 21 days before being leached with 5 liters of distilled water yielding 3 inches of drainage water for the surface exposed.

The results may be summarized as follows:

1. All nitrogen applied as nitrate was leached.

2. One-third of the ammonium nitrogen applied as ammonium sulfate or ammonium nitrate was leached.

3. The leaching of the ammonium ion from ammonium phosphate was very low.

4. Ammonium carbonate was retained very efficiently by the soil until nitrification began.

5. Urea leached as urea to the extent of 35% and 16% after 1- and 4-day incubation periods, respectively. Ammonium nitrogen was retained very efficiently by the soil until nitrification began. Then, as with ammonium carbonate, both ammonium and nitrate nitrogen leached.

6. Very little difference was noted in the nitrogen content of the leachates from the untreated cultures and the cultures treated with the insoluble organic fertilizers.

A second series of similar cultures using four soil types were treated with sodium nitrate, ammonium sulfate, urea, castor pomace, and no treatment. All cultures were incubated for 4 days before they were leached with sufficient water to effect a quantity of drainage equivalent to 3 inches of water for the surface exposed. The leachates were analyzed for ammonium, urea, and nitrate nitrogen.

The results may be summarized as follows:

1. The nitrates leached almost completely, except from Norfolk fine sandy loam which retained 27.8% in the soil.

2. Forty per cent of the ammonium nitrogen applied as ammonium sulfate leached from Norfolk sand, while insignificant amounts leached from the other soils.

3. No urea was found in any of the leachates.

4. The castor pomace treatment gave very similar results to the no-treatment cultures after 4 days.

5. The leachates showed greater acidity than did the soils.

6. The pH value of the soil was increased by leaching.

7. The most significant effect on the acidity of the soil of any of the materials added was induced by urea which materially raised the pH.

LITERATURE CITED

1. ASSOC. OFFICIAL AGR. CHEMISTS. Official and Tentative Methods of Analysis. Ed. 4. 1935.
2. BIZZELL, J. A. Removal of plant nutrients in drainage waters. Jour. Amer. Soc. Agron., 18:130–136. 1926.
3. BOUYOUCOS, G. J. A comparison of the hydrometer method and the pipette method for making mechanical analysis of soils, with new directions. Jour. Amer. Soc. Agron., 22:747–751. 1930.
4. COLLISON, S. E. Citrus fertilizer experiments. Fla. Agr. Exp. Sta. Bul. 154: 8–15. 1919.
5. ECKART, C. F. Lysimeter experiments. Hawaiian Sugar Planters' Assoc., Exp. Sta., Div. Agr. and Chem., Bul. 19:1–31. 1906.
6. MOORES, C. A., MACINTIRE, W. H., and YOUNG, B. J. The recovery of soil nitrogen under various conditions as measured by lysimeters of different depths. Tenn. Agr. Exp. Sta. Bul. 138. 1927.
7. MORGAN, M. F. Soil changes resulting from nitrogenous fertilization. Conn. Agr. Exp. Sta. Bul. 384. 1936.
8. PARKER, F. W. Relation between the equivalent acidity of sources of nitrogen and their efficiency in potato fertilization. Amer. Potato Jour., 3:60–62. 1935.

9. Purvis, E. R., and Ruprecht, R. W. Soil and fertilizer studies with celery. Fla. Agr. Exp. Sta. Ann. Rpt. 1937.
10. Schollenberger, C. J., and Dreibelbis, F. R. Analytical methods in base exchange investigations of soils. Soil Science, 30:161–173. 1930.
11. Snell, F. D., and Snell, C. T. Colorimetric methods of analysis. New York: D. Van Nostrand and Co. 1936.
12. Tidmore, J. W., and Williamson, J. T. Experiments with commercial nitrogenous fertilizers. Ala. Agr. Exp. Sta. Bul. 238. 1932.
13. Waksman, Selman A. The Principles of Soil Microbiology. Baltimore: Williams and Wilkins Co. 1927.

THE ANALYSIS OF VARIANCE WITH SPECIAL REFERENCE TO DATA EXPRESSED AS PERCENTAGES[1]

ANDREW CLARK AND WARREN H. LEONARD[2]

THERE is considerable diversity of opinion and practice among experimental workers in regard to the validity and use of generalized standard errors, especially with the analysis of variance when applied to complex or pooled experiments. Some workers apply these statistical methods in a mechanical way with little regard to the type of data involved, scant attention being given to any inquiry as to whether the data meet the fundamental assumptions upon which the validity of generalized standard errors depend. On the other hand, certain cautious experimenters sense that their data may not admit combination for the construction of a generalized standard error and, without testing to determine whether their fears are realized, adopt what often is a too conservative policy with respect to pooled estimates of error.

The basic assumption (6)[3] upon which the validity of a generalized standard error depends is that the contributions to experimental error of the several variates constituting the sample, drawn from what might be a distinctly heterogeneous population due to significant-imposed treatments, are in agreement with the sampling theory for a normal population.

COMBINATION OF DISCRETE DATA

There are two principal reasons why experimental data will not or may not justify their combined use to provide a valid estimate of a generalized experimental error. First, the data may be discrete and represent either a Bernoulei (binomial) series or a Lexis series wherein each variate represents a certain number of observations of a given type or condition out of a total number of trials or cases (n). The variance of a single variate of this type is npq It is clearly dependent on p, the estimated ratio of existence of the type or condition in question, as well as upon n, the total number of trials or cases upon which each variate is based. Bliss (1, 2), Salmon (8), Cochran (4), and others have recognized that each variate in discrete data of this kind does not, therefore, have the same opportunity to contribute equally to a general experimental error. Bliss indicates that R. A. Fisher has supplied a mathematical transformation[4] for such data which will equalize the estimated variance of each variate, leaving it functionally dependent only on n, the total number of trials.

In this transformation each estimate of p is replaced by $Sin^2\Theta$, whence,

$$\Theta = \mathrm{Sin}^{-1}\sqrt{p} \text{ or } \tfrac{1}{2}\,\mathrm{Cos}^{-1}(1-2p).$$

[1]Contribution from the Agronomy Section, Colorado Agricultural Experiment Station, Fort Collins, Colo. Published with the approval of the Director. Received for publication October 24, 1938.

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[3]Reference by figures in parenthesis is to "Literature Cited", p. 66.

[4]So far as the writers know, Fisher's method of obtaining this transformation has not been published.

Suppose the standard error of an individual variate, *np*, is estimated by $\sqrt{npq} = n \cdot dp$. Differentiation of the transformation gives $d\Theta = dp/2\sqrt{p(1-p)}$. By substitution, one obtains $d\Theta = 1/2\sqrt{n}$ as the estimated standard error of Θ. This expression is clearly seen to be dependent on *n* only. It is well-known that $V(np)$, the variance of *np* is *npq*, or, where the data have been transformed to percentages, $V(p) = pq/n$. It is obvious that the variance changes materially for different values of *p*, being a maximum when $p = 0.50$, or 50%, and approaching zero as *p* nears either 0.0 or 1.0. However, $V(\Theta)$, the variance of an individual (Θ), equals $1/4n$ and remains constantly equal to the maximum value of $V(p)$ over the entire range of values of Θ from 0 to $\Pi/2$, where Θ is measured in radians. Fig. 1 illustrates the effect of the transformation on the variance of a single variate.

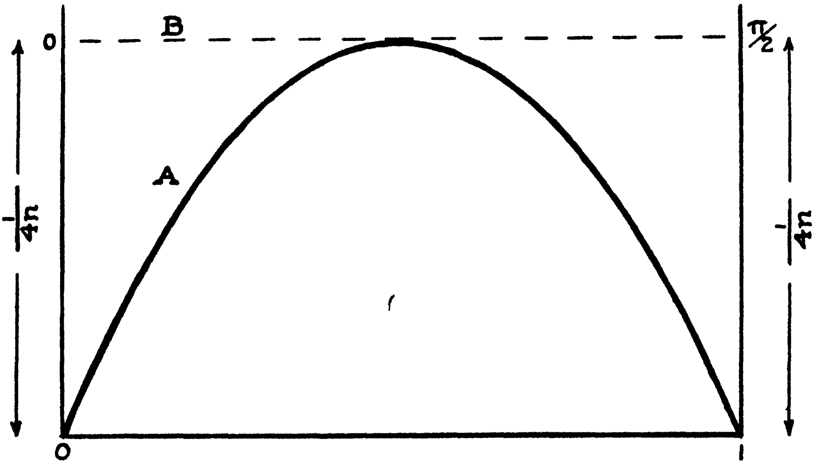

FIG. 1.—The effect of the transformation on a single variate. Curve A indicates how $V(p) = pq/n$ varies as *p* varies from 0 to 1. Line B shows $V(\Theta) = 1/4n$ as constant as Θ varies from 0 to $\Pi/2$.

DEVELOPMENT OF THE TRANSFORMATION

Let dp represent the standard error of p, i.e., $\sqrt{\frac{pq}{n}}$. Then it is desired to determine a transformation, $p = f(\Theta)$, such that $d\Theta$, representing the standard error of Θ, will be a constant or functionally dependent upon *n* only. Upon differentiation one obtains $dp = f^1(\Theta)d\Theta$. It is also clear that $dp = \sqrt{\frac{pq}{n}} = \sqrt{\frac{f(\Theta)\ (1-f(\Theta))}{n}}$ and, combining the above expressions, $f^1(\Theta)d\Theta = \sqrt{\frac{f(\Theta)\ (1-f(\Theta))}{n}}$. The requirement that $d\Theta$ be a constant, say $1/C$, is next satisfied so that the above equation becomes

$$\frac{f^1(\Theta)}{\sqrt{\frac{f(\Theta)\ (1-f(\Theta))}{n}}} = C.$$

This differential equation is solved, arbitrarily making $C = 2\sqrt{n}$. As a particular solution, one obtains $\text{Cos}^{-1}\ (1-2f(\Theta)\ ) = 2\Theta$, whence $f(\Theta) = \frac{1-\text{Cos}\ 2\Theta}{2} = \text{Sin}^2\ \Theta$. This is the transformation which Fisher sent to Bliss (1, 2). It is evident that the choice of a value for C defines the range of the variable (Θ) and consequently its variance.

EMPLOYMENT OF THE TRANSFORMATION

It is clear then that the above transformation must necessarily be applied to discrete data of the type under consideration if it is intended to employ the analysis of variance or any other means that leads to the construction of a generalized standard error. In his original paper (in Russian), Bliss (1) gives a convenient table for the transformation of percentage values to angles, the latter being measured in degrees. However, by use of the form, $\Theta = \frac{1}{2}\ \text{Cos}^{-1}\ (1-2p)$, an ordinary table of trigonometric functions will suffice quite well. When the transformed values of Θ are measured in degrees, it must be remembered that the standard error of Θ will become $\frac{180}{\Pi} \cdot \frac{1}{2\sqrt{n}}$.

It is evident that the variance of Θ is discontinuous under this transformation at the end points of the range, i.e., when p is either 0 or 1. No consideration has been given this circumstance in this paper, although it has been advocated that p values of 0 and 1 be arbitrarily replaced by $\frac{1}{4n}$ and $\frac{4n-1}{4n}$, respectively. However, when a p value of 0 or 1 occurs repeatedly under a given treatment variant under replication, it might be wise to withdraw that portion of the data from the statistical analysis.

It is very important to note that even though the above transformation is applied, it is necessary that n, the total number of trials, be kept constant or very close thereto for any generalized standard error to be valid. With data expressed in terms of percentages, an experiment may have all appearance of being completely orthogonal, but when each percentage is based on a different value of n, it will really be entirely unorthogonal. Any attempt to employ the analysis of variance must take that fact into account.

TYPES OF PERCENTAGE DATA

In his article on this transformation, Bliss (1) intimates that data expressed as percentages are the source of violation of the basic assumption that underlies the analysis of variance, such data being the type of which the transformation should be applied. This is apt to mislead the experimenter *since the type of discrete data in hand, rather than its expression in terms of percentages, is the criterion for determining a need for the employment of the transformation*. As data expressed in percentages have long troubled experimental workers, it would seem worthwhile to classify types of percentages indicating the nature of each type.

First, continuous data resulting from an experimental study may be expressed as percentages when each variate is divided by an arbitrary constant value, whereby each variate becomes a percentage of some standard or average. Clearly such a procedure merely transforms the unit of measurement. Percentages of this type should be treated statistically exactly as if the data were in their raw form. For example, yield data might be expressed in percentage of the check instead of actual yield in pounds.

Second, continuous data are often expressed in percentages to show concentrations because a comparison of concentrations is the principal objective of the study. This type of percentage is very common. Some examples are: Seed purity given by weight of pure seed/total weight of seed, leafiness given by leaf weight/total plant weight, protein content given by weight of protein/total weight, sugar content given by weight of sugar/weight of root. Such concentrations should not, as a rule, be subjected to any transformation to equalize the variance. However, the technic of each problem that affords percentage data must be considered carefully in deciding whether or not a transformation should be employed to remove a given type of heterogeneity. For instance, percentages of vegetative cover within quadrats estimated at successive time intervals are likely to be heterogeneous when combined. This circumstance would arise because a change in percentage is directly dependent on both the amount of a type of vegetation within the quadrat and also upon its competition with other types This functional dependence can be expressed by the differential equation $\frac{dp}{dt} = cp\ (1-p)$ which, when solved, affords the transformation $t = \log \frac{1}{1-p}$.

There is a third type of percentage, where the original data are discrete, being based upon a determinate number of trials or cases (n). It is to this type of percentage data that the transformation, $p = \mathrm{Sin}^2\ \Theta$, should be applied to construct an estimate of a generalized standard error. Illustrations of this kind of percentage data are as follows: Germination percentages given by number of seeds germinated/total seeds, disease percentages given by number of plants diseased/total plants, etc.

HETEROGENEITY OF SETS OF ESTIMATED VARIANCES

A second general source of difficulty which frequently prevents a generalized standard error from being a valid estimate is the fact that the different variants of a recognized source of variation incorporated into the experimental design may produce important interaction effects with the unrecognized and uncontrolled sources of variation actually affording the experimental error. Such a situation results in differences of such magnitude in the contributions of the data under the several variants of a given source of variation as are inconsistent with what could be expected on the basis of sampling. It has been recognized that experimental data from different localities or from

different years may often lack sufficient basic homogeneity to admit pooling to form a generalized standard error. However, it is important to realize that different imposed treatment variants may also alter the basic homogeneity of the data to such an extent that the experimental error provided by the analysis of variance may be entirely invalid for any practical use.

Therefore, it is often necessary to subject to scrutiny the basic homogeneity of experimental data to which it is desired to apply the analysis of variance. Stevens (10) has given a method to test the homogeneity of a set of variances which should be applied in case the data should at all suggest heterogeneity among the several variants of any source of variation This test, devoid of its mathematical development, is next reproduced.

Let V_r, with $r = 1, 2 \ldots, k$, represent the contributory variances of the k-variants of a source of variation to the construction of a generalized standard error, V, where $V = \frac{S(n_r - 1)V_r}{S(n_r - 1)}$.

In this case, n_r represents the number of replications within the rth variant, the summations being extended over all the k-variants Then the expression $\frac{S(n_r - 1)(V_r - V)^2}{2V^2}$ is distributed approximately as X^2 with k-1 degrees of freedom (8). Since this modified X^2 is sensitive to differences between variances, it is valuable for testing the hypothesis that each of a set of variances estimates a single variance formed when they are pooled and averaged.

In the mathematical development of this test, it was assumed that each sub-population was normally distributed. Consequently, $n_r - 1$ in the expression for X^2 represents the corresponding degrees of freedom, i.e., the number of variates diminished by one. Some modification is necessary in order to make a more extensive use of the test, as in a complex experiment. The principle of employing the number of degrees of freedom as a multiplying factor must still be maintained. Suppose that variances to other sources of variation in an orthogonal design are to be removed from each of the variances the aggregate of which are being tested for homogeneity. It is necessary to diminish $n_r - 1$ by the corresponding degrees of freedom associated with each of the variances so removed. Some data published by Salmon (8) may be used as an illustration Ten wheat varieties were each tested with 20 different collections of bunt in two replications. In this case, the number of variates under each of the several varieties would be $n_r = 40$. Instead of using $n_r - 1 = 39$, it is necessary to diminish the degrees of freedom that correspond to bunt collections because the variance due to this source was removed in each instance. Therefore, in this problem the multiplying factor employed to form the modified X^2 is $39 - 19 = 20$, instead of strictly $n_r - 1$. If the variance due to soil blocks were removed also, it would be necessary to withdraw one more degree of freedom, and thus leave 19.

It should be mentioned that a simpler but inconclusive test will often obviate the need of the homogeneity test outlined above. The investigator can simply divide the largest V by the smallest V in the

set of variances under consideration to form F (9). If this value of F is not significant, the homogeneity of the set of variances may be assumed. Although this test is sufficient to prove homogeneity, it is not at all a necessary condition. When F is significant the X^2 criterion should be employed. It might also be stated that the homogeneity test outlined here and due to Stevens (10) is identical in principle to that devised by Brandt and given by Snedecor (9). Also it should be added that Wishart (11) regards the homogeneity test developed by Bartlett to be superior to and more sensitive than that presented here, particularly if the number of degrees of freedom associated with each variance is small.

ILLUSTRATIVE EXAMPLE FOR HOMOGENEITY TEST

As an adequate illustration of the objectives of this article, it is proposed to analyze that portion of the original percentage data that Salmon (8) saw fit to publish. Table 1 gives these data showing percentages of infection in 10 different wheat varieties with 20 bunt collections at Kearneysville, West Virginia, in 1935. This material is admirably suited as an illustrative example because (a) the percentages were derived from discrete data on infection counts with 200 trials as the value of n in each case; and (b) there is a lack of basic homogeneity in the data under the several variants of at least one of the principal sources of variation, which fact prevents at least that all of the data be combined for the construction of one estimate of experimental error. However, it will be shown that the data are not nearly so incompatible as Salmon (8) indicates, but that a large proportion of them can be pooled to provide a perfectly valid estimate of error.

In the first place, the percentages given in Table 1 are exactly the type that necessitate the employment of the transformation, $p = \mathrm{Sin}^2\,\Theta$. The transformed data are presented in Table 2.[5]

In order to investigate whether these transformed data may be subjected to an analysis of variance, the estimate of variance within each variety is first computed to measure the variation of each pair of replicates about the mean of each pair. The number of degrees of freedom will be 39−19=20, since only variance between bunt collections is removed. Table 3 presents the variances for the different varieties of wheat, which are subsequently subjected to the homogeneity test, together with the standard errors for the varieties.

The computation for the homogeneity test is as follows:

$X^2 = \dfrac{S(n_r\ 1)\,(V_r - V)^2}{2V^2} = \dfrac{20 \times 909.5185}{(2 \times 23.9586)^2} = 15.844$. This is treated as X^2 with nine degrees of freedom. A table of probabilities for X^2 values indicates that the probability of obtaining, as a result of sampling, a value as large or larger than 15.844 to be approximately 0.104. The result is not significant, but it suggests possible danger in the con-

[5]To illustrate the use of a table of cosines for the transformation of a percentage to an angle, consider $p = 86.6\% = 0.866$ for collection 1 and replication 1 for Hybrid 128. Then as $\Theta = \frac{1}{2}\,\mathrm{Cos}^{-1}\,(1-2p)$, one obtains $\Theta = \frac{1}{2}\,\mathrm{Cos}^{-1}\,(1-1.732) = \frac{1}{2}\,\mathrm{Cos}^{-1}\,(-0.732)$. A table of cosines gives $\mathrm{Cos}^{-1}\,(-0.732) = 137.06°$. Then, $\Theta = \frac{1}{2}\,(137.06°) = 68.53°$.

TABLE 1 —*Percentage infection in different varieties of wheat with 20 collections of bunt at Kearneysville West Virginia, in 1935*

Bunt collection No.	Hybrid 128		Turkey		Minturki		Oro		Ridit		Albit		Martin		Hohenheimer		White Odessa		Hussar		Av % bunt
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
1	86.6	80.7	8.3	6.5	79.1	72.8	0.0	0.9	6.3	3.9	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.5	0.6	17.5
2	76.4	95.2	89.0	84.3	90.6	84.3	2.5	3.6	8.7	2.2	92.4	90.6	18.4	16.0	0.0	1.4	97.5	98.1	81.0	74.9	55.4
3	94.9	93.3	3.3	6.0	87.9	75.4	1.5	0.0	6.0	0.7	93.7	90.1	84.5	64.8	0.0	0.0	97.8	94.4	0.0	0.7	44.8
4	91.0	91.7	81.7	87.2	92.0	82.6	[illegible]	6.3	4.1	3.1	14.0	4.5	0.0	3.0	0.0	0.0	75.9	84.7	0.0	0.7	36.3
5	83.7	90.2	7.5	2.4	60.6	80.9	0.6	1.6	3.9	3.6	4.2	3.2	0.0	2.2	2.4	2.5	0.7	0.0	0.0	0.7	17.7
6	88.9	92.2	5.6	7.4	52.5	39.4	1.1	0.0	2.2	0.0	0.0	0.0	5.0	0.6	0.0	0.0	0.0	0.0	1.6	0.0	14.9
7	97.5	97.9	13.7	9.0	55.6	44.3	0.0	0.8	2.0	1.8	0.0	0.9	1.4	0.8	7.1	0.0	2.0	1.9	0.0	0.0	16.9
7a	81.5	92.2	17.4	9.8	55.4	83.3	1.2	4.4	5.2	4.9	85.2	82.5	61.1	62.0	0.9	5.6	68.8	86.5	1.1	0.0	43.0
8	92.8	91.5	8.5	8.4	30.3	30.4	1.6	1.1	1.2	0.0	0.0	0.6	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5
9	97.3	92.6	15.4	3.8	17.2	11.7	3.3	0.0	3.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	8.4	0.8	2.5	0.0	12.9
10	93.7	83.3	5.8	1.3	71.2	63.7	3.1	0.0	4.2	3.8	92.1	79.6	77.9	77.0	0.9	0.0	90.4	74.6	1.2	0.8	41.3
11	83.0	77.8	3.8	1.1	70.6	69.9	0.5	1.7	6.8	5.5	2.1	3.9	0.6	0.9	0.0	0.0	1.3	0.0	0.0	0.0	16.6
12	82.1	79.5	9.8	4.7	49.5	75.2	0.0	0.0	15.5	0.0	50.0	76.5	75.5	74.5	0.0	0.0	74.1	79.1	2.8	0.6	37.7
13	80.2	80.7	5.6	10.9	61.9	60.9	0.0	2.0	0.8	10.8	0.6	0.0	2.0	0.0	0.1	12.2	2.1	7.3	1.2	0.0	17.3
14	78.3	77.7	82.5	54.7	76.4	79.7	3.5	7.5	12.7	12.5	81.9	87.2	75.5	76.4	1.1	1.3	88.8	91.2	62.6	69.7	56.1
15	80.0	95.5	10.3	7.3	79.7	83.8	2.4	1.1	10.1	2.2	78.8	90.6	70.1	60.2	0.0	0.0	85.8	98.0	2.1	0.0	43.4
32	85.8	97.8	76.5	92.6	90.9	80.9	59.8	75.0	14.4	5.2	0.0	0.0	2.3	2.1	0.0	0.0	0.0	0.0	1.0	3.3	34.4
51	94.2	95.5	28.3	21.5	45.1	40.0	0.6	1.2	4.8	4.7	0.8	2.6	0.0	0.0	0.0	0.0	5.1	1.4	0.5	0.0	17.4
157	75.0	86.3	52.4	92.1	75.3	85.3	2.2	0.9	1.4	1.0	89.2	85.0	47.0	82.2	0.0	0.0	83.4	90.5	45.5	37.6	51.6
189	87.3	94.6	79.5	92.0	81.1	80.2	7.5	4.7	4.9	6.1	91.9	94.6	71.0	78.0	2.9	1.2	96.4	96.7	53.2	70.2	59.7
Average	87.2	90.7	43.7	46.2	76.9	77.9	3.7	4.4	4.5	4.2	28.5	29.1	23.0	22.5	0.4	0.8	33.3	33.4	10.9	10.6	
Grand av	89.0		45.0		77.4		4.1		4.4		28.8		22.8		0.6		33.4		10.8		

TABLE 2.—*Percentage data from Table 1 transformed to degrees by the transformation, $p = sin^2\Theta$.*

Bunt collection No.	Hybrid 128		Turkey		Minturki		Oro		Ridit		Albit		Martin		Hohenheimer		White Odessa		Hussar	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	68.53	63.94	16.74	14.77	62.80	58.56	0.00	5.44	14.54	11.39	0.00	0.00	8.33	0.00	0.00	0.00	0.00	0.00	4.05	4.44
2	60.04	77.34	70.63	66.66	72.15	66.66	9.10	10.94	17.16	8.53	74.00	72.15	25.40	23.58	0.00	6.80	80.90	82.08	64.16	59.93
3	76.95	75.00	10.47	14.18	69.64	60.27	7.04	0.00	14.18	4.80	75.46	71.66	66.81	53.61	0.00	0.00	81.47	76.31	0.00	4.80
4	72.54	73.26	64.67	69.04	73.57	65.35	7.04	14.54	11.68	10.14	21.97	12.25	0.00	9.98	0.00	0.00	60.60	66.97	0.00	4.80
5	66.19	71.76	15.80	8.91	51.12	64.08	4.44	7.27	11.39	10.94	11.83	10.31	0.00	8.53	8.91	9.10	4.80	0.00	0.00	4.80
6	70.54	73.78	13.69	15.79	46.43	38.88	6.02	0.00	8.53	0.00	0.00	0.00	12.92	4.44	0.00	0.00	0.00	0.00	7.27	0.00
7	80.90	81.67	21.72	17.46	48.22	41.73	0.00	5.13	8.13	7.71	0.00	5.44	6.80	5.13	15.45	0.00	8.13	7.92	0.00	0.00
7a	64.52	73.78	24.65	18.24	67.54	65.88	6.29	12.11	13.18	12.79	67.37	65.27	51.41	51.94	5.44	13.68	56.04	68.44	6.02	0.00
8	74.44	73.05	16.05	16.85	33.40	33.46	7.27	6.02	6.29	0.00	0.00	4.44	7.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	80.54	74.21	23.11	11.24	24.50	20.00	10.47	0.00	9.08	0.00	0.00	5.13	0.00	0.00	0.00	0.00	16.85	5.13	9.10	0.00
10	75.46	65.88	13.04	6.55	57.54	52.95	10.14	0.00	11.83	11.24	73.57	63.15	61.96	61.34	5.44	0.00	71.95	59.74	6.29	5.13
11	65.65	61.89	11.24	6.02	57.17	56.73	4.05	7.49	15.12	13.56	8.33	11.39	4.44	5.44	0.00	0.00	6.55	0.00	0.00	0.00
12	64.97	63.08	18.24	12.52	44.71	60.13	0.00	0.00	23.19	0.00	45.00	61.00	60.33	59.67	0.00	0.00	59.41	62.80	9.63	4.44
13	63.58	63.94	13.69	19.28	51.88	51.30	0.00	8.13	5.13	19.19	4.44	0.00	8.13	0.00	14.30	20.44	8.33	15.68	6.29	0.00
14	62.24	61.82	65.27	47.70	60.94	63.22	10.78	15.89	20.88	20.70	64.82	69.04	60.33	60.94	6.02	6.55	70.45	72.74	52.30	55.49
15	63.44	77.75	18.72	15.62	63.22	66.27	8.91	6.02	18.53	8.53	62.58	72.15	56.85	56.29	0.00	0.00	67.86	81.87	8.33	0.00
32	67.86	81.47	61.00	74.21	72.44	64.08	50.65	60.00	22.30	13.18	0.00	0.00	8.72	8.33	0.00	0.00	0.00	0.00	5.74	10.47
51	76.06	77.75	32.14	27.63	42.19	39.23	4.44	6.29	12.66	12.52	5.13	9.28	0.00	0.00	0.00	0.00	13.05	6.80	4.05	0.00
157	60.00	68.28	46.38	73.68	60.20	67.45	8.53	5.44	6.80	5.74	70.81	67.21	43.28	65.05	0.00	0.00	65.96	72.05	42.42	37.82
189	69.12	76.56	63.08	73.57	64.23	63.58	15.89	12.52	12.79	14.30	73.46	76.56	57.42	62.03	9.81	6.29	75.56	79.53	46.83	56.91
Mean*	69.224	71.811	31.111	30.499	56.200	54.991	8.553	0.167	13.215	9.268	32.939	33.822	27.020	26.815	3.269	3.134	37.446	37.903	13.624	12.452
Grand mean	70.517		30.805		55.595		8.859		11.241		33.380		26.918		3.201		37.674		13.038	

*Mean values of Θ by varieties.

TABLE 3 —*Variances for varieties (transformed data)*

Variety	V_r	$s_r = \sqrt{V_r}$	$(V_r - V)^2$
Hybrid 128	27 2695	5 22	10 9621
Turkey	45 3931	6 74	459 4278
Minturki	22 4772	4 74	2 1945
Oro	17 1502	4 14	46 3543
Ridit	32 7946	5 73	78 0749
Albit	18 4381	4 29	30 4759
Martin	27 7772	5 27	13 5817
Hohenheimer	10 8210	3 29	172 5965
White Odessa	23 1647	4 81	0 6303
Hussar	14 2005	3 77	95 2205

$V = \frac{S(V_r)}{10} = 23\ 9586$ $S(V_r - V)^2 = 909\ 5185$

solidation of the data It indicates that the variances within the several collections of bunt should be subjected to a like test Table 4 presents the pertinent statistics for the 20 bunt collections

TABLE 4 —*Variances for bunt collections (transformed data)*

Bunt collection No	V_r	$s_r = \sqrt{V_r}$	$(V_r - V)^2$
1	7 5992	2 75	267 6300
2	23 2495	4 82	0 5028
3	24 0525	4 90	0 0088
4	20 1750	4 49	14 2156
5	18 8544	4 34	26 0520
6	15 2837	3 91	75 2539
7	17 9242	4 23	36 4140
7a	21 3102	4 62	7 0140
8	5 7819	2 40	331 3924
9	32 8461	5 73	67 8999
10	27 9804	5 29	16 1749
11	5 4522	2 34	342 4868
12	55 3353	7 44	984 4973
13	25 6154	5 06	2 7450
14	18 7053	4 32	27 5972
15	34 4620	5 87	110 3214
32	31 1374	5 58	51 5353
51	5 6394	2 38	335 5931
157	71 1112	8 43	2223 3677
189	16 6565	4 08	53 3207

$V = \frac{S(V_r)}{20} = 23\ 9586$ $S(V_r - V)^2 = 4974\ 0227$

The homogeneity test gives $\frac{S(n_r-1)\ (V_r - V)^2}{2V^2} = \frac{10 \times 4974\ 0227}{2(19\ 5959)^2} =$ 64 765 A table of probabilities shows that the probability of obtaining a value of 36 191 for 19 degrees of freedom to be 0 01 Hence, the obtained value, 64 765, must be interpreted as extremely significant It clearly indicates that the variances within the several bunt collections cannot be estimates of the same value As a result, it can only be concluded that the data considered cannot be combined in their entirety in an analysis of variance

However, a critical examination of the data indicates that the construction of a useful generalized standard error may still be possible. It seems that the extreme lack of homogeneity exhibited by the variances within bunt collections is principally due to but two collections, i.e., Nos. 12 and 157. When the data afforded by these two collections are neglected altogether, the remainder of the data being re-subjected to the homogeneity test, it is found that the variances within varieties provide a modified $X^2 = 7.692$, which interpreted on the basis of nine degrees of freedom has a probability 0.57 of occurrence. The homogeneity test applied to the variances within the 18 remaining bunt collections shows a modified $X^2 = 18.669$ which, interpreted for 17 degrees of freedom, has an approximate probability 0.36 of occurrence.

It is now evident that the vast majority of the original data can be treated by the analysis of variance, the results of which are given in Table 5.

TABLE 5. *Complete analysis of variance (transformed data).*

Variation due to	Sums of squares	Degrees of freedom	Mean square	Standard error	F
Blocks ..	33 72	1	33 72	-	2 00
Varieties	149 809 43	9	16,645 49	—	988 45*
Collections	55 833 74	17	3 284.34	--	195 03*
Varieties × collections	91,781 71	153	599 88	-	35 62*
Varieties × blocks	229 51	9	25 50	--	1 51
Collections × blocks	689 05	17	40 53	--	2 41*
Error	2 576 38	153	16 84	4 1037	- -
Total	300,953 54	359			

*Exceeds the 1% point

The standard errors for varieties, bunt collections, and varieties × bunt collections, are as follows:

$$s_v = \frac{4.1037}{\sqrt{36}} = 0.68$$

$$s_b = \frac{4.1037}{\sqrt{20}} = 0.92$$

$$s_{bv} = \frac{4.1037}{\sqrt{2}} = 2.90$$

SAMPLING THEORY INVOLVED

In this experiment where $n = 200$, the total heads observed from each row, the theoretical variance of an individual observation transformed from p to Θ, would be $V = \frac{1}{4n} = \frac{1}{800}$ for Θ measured in radians. Since Θ is given in degrees here, the standard error must be multiplied by $180/\Pi$ so that $V = \frac{1}{4n}\left(\frac{180}{\Pi}\right)^2 = 4.1035$.

There is a serious discrepancy between this value and 16.84, the mean residual or error variance actually afforded by the data. Salmon (8) noted a comparable discrepancy in treating the raw percentage data but rather unfairly intimates that the binomial distribution strictly applies only to coin-tossing problems or like schemata. Without doubt, the principal explanation that sampling theory based on a simple binomial distribution fails to account for the large experimental variance obtained is because the population sampled is not distributed in an ordinary binomial distribution due to the fact that the head rather than the plant is taken as the unit of observation. The correlation between infection and heads from the same plant will be extremely high. To illustrate the effect of this correlation in increasing the variance, consider a sample of 200 heads taken from 50 plants, 4 heads from each plant For an assumed perfect correlation, the theoretical variance of an obtained percentage of infection would be $\frac{4pq}{n}$ instead of $\frac{pq}{n}$ as expected from sampling one head from each of 200 plants (4, 6).

Therefore, the method of sampling by observing heads can be held accountable for the fact that the obtained variances are much greater than the theoretical variance expected from simple sampling. They also account for the lack of uniformity of the number of heads to the number of plants sampled. Very clearly this practice might produce a type of heterogeneity in the data which precludes it in the aggregate from providing a single valid standard error of estimate. Also, the fact that certain check varieties may be included which are extremely susceptible to infection may produce a distinct heterogeneity due to an abnormal variety population.[6]

CONCLUSIONS

1. Discrete data representing counts of a given type, condition, or attribute and based on a determinate number of trials should be subjected to the transformation $p = \text{Sin}^2\ \theta$ where it is proposed to combine them in any way to construct a generalized standard error. Whether such data represent the actual counts or percentages derived from them does not alter the situation.

2. The above transformation was suggested by R. A. Fisher. Its mathematical development based upon the need for equalizing variances is here presented.

3. Percentage data in general are classified into three types in order to indicate more clearly when and when not to employ this transformation.

4. The need is emphasized for subjecting data under imposed sources of variation to a homogeneity test when it is proposed to treat the combined data by an analysis of variance.

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[6]Correspondence with Dr. S. C. Salmon indicates that the data at hand resulted from sampling not more than two heads per plant. In view of this fact, a lesser emphasis than is indicated in the body of this paper should be placed upon sampling technic as the reason for a high experimental variance. Likewise, Salmon's explanation of variable experimental conditions, including soil moisture and temperature as affecting variances, assumes an added significance.

5. Some of the reasons are presented for the heterogeneity of variances which sometimes results under the several variants of an imposed source of variation. In particular it is suggested that this undesirable type of heterogeneity appearing in smut data is attributable to lack of uniformity in sampling due to the choice of the head rather than the plant as the sampling unit.

6. It is also indicated through illustration that even though data in their entirety exhibit such heterogeneity as to make an analysis of variance invalid, it may be possible to eliminate the data under certain variants of a source of variation and still combine the majority of the data for the determination of a valid generalized standard error with but little loss of information and generality.

LITERATURE CITED

1. BLISS, C. I. The analysis of field experimental data expressed in percentages. Leningrad: Plant Protection Bul. 12, U.S.S.R. 1937.
2. ———. The transformation of percentages for use in the analysis of variance. Ohio Jour. Sci., 38:No. 1, 1938.
3. BARTLETT, M. S. Properties of sufficiency in statistical tests. Proc. Roy. Soc., A, 160:268–282. 1937.
4. COCHRAN, W. G. Some difficulties in the statistical analysis of replicated experiments. Emp. Jour. Agr., 6:157 175. 1938
5. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 5. 1934. (Pages 70 and 102.)
6. IRWIN, J. O. Mathematical theorems involved in the analysis of variance. Jour. Roy. Stat. Soc., 94, Part II. 1931.
7. POWERS, L., and CLARK, A. Failure of chromosome pairing as evidence of secondary diploidy in *Zea mays*. Jour. Gen., 35:301–313. 1937.
8. SALMON, S. C. Generalized standard errors for evaluating bunt experiments with wheat. Jour. Amer. Soc. Agron., 30:647–663. 1938.
9. SNEDECOR, G. W. Statistical Methods. Ames, Iowa: Collegiate Press. 1937. (Page 196.)
10. STEVENS, W. L. Heterogeneity of a set of variances. Jour. Gen., 33:398 399. 1936.
11. WISHART, J. Field experiments of factorial design. Jour. Agr. Sci., 28:299–306. 1938.

THE RESPONSE OF QUACK GRASS TO VARIATIONS IN HEIGHT OF CUTTING AND RATES OF APPLICATION OF NITROGEN[1]

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QUACK grass, *Agropyron repens* (*L.*) Beauv., occupies large land acreages in Michigan and other northern states and has become a plant of considerable importance. The plant has a tenacious rhizomatic habit of growth and is difficult to eradicate. Several methods of quack grass control are practiced nearly all of which involve the exhaustion of root reserves and removal of photosynthetic tissue.

The following paper reports a study of defoliation of quack grass cultures, some high and some low in nitrogen. These were defoliated at various heights for a considerable period of time and the various effects on roots and rhizomes and new top growth were observed.

REVIEW OF LITERATURE

A study of the literature (2, 3, 4, 5)[3] reveals that root and rhizome development and yield of grasses are influenced by the cutting treatment In general, the more frequent and complete the defoliation the less is the yield of roots, rhizomes, and tops. Severe defoliation and application of nitrogen to grasses having abundant reserves stimulates a vegetative response, the carbohydrate reserves are rapidly consumed, and with slight opportunity for replenishment they often become the principal factors limiting growth.

As pointed out by Dexter (1) it is difficult to exhaust the organic reserves of quack grass or to place it in a condition where it is susceptible to injury by defoliation.

METHODS AND MATERIALS

On July 12, 1937, ten quack grass rhizome segments, 2 to 3 inches long, were placed in each of 80 10-inch clay pots. The plants were grown in the greenhouse at East Lansing, Michigan. Sand cultures were used throughout the experiment. The plants were supplied with a three-salt nutrient solution designated as type IR_2S_4.[4] The nutrient solution was applied by the slop culture technic.

Growth of the plants was steady and at the end of two months the pots were well filled with vigorous plants showing good rhizome development. On September 20, the nutrients were flushed out of 40 of the pots by repeated applications of tap water, the water being allowed to drip through the pot before each succeeding application. From this date to the conclusion of the experiment these plants were grown in a nutrient solution containing no nitrogen. This was accomplished by substituting calcium chloride for calcium nitrate in equal molar quantities.

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[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article 338 (N.S.). Received for publication November 7, 1938.

[2]Assistant in Crops and Research Associate, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 76.

[4]LIVINGSTON, B. E. A plan for cooperative research on the salt requirements of agricultural plants. Ed. 2. 1919.

The other 40 cultures were supplied continuously with available nitrogen. For convenience, these cultures will be known as minus and plus nitrogen cultures, respectively.

On October 29, 1937, three plus and three minus nitrogen cultures were washed free of sand. Green and dry weight determinations were made on the roots, rhizomes, and tops. These cultures served as initial checks. On the same date 30 plus and 30 minus nitrogen cultures were divided each into five groups of six cultures each. For each of the five groups, both plus and minus nitrogen, a different cutting practice was followed. On October 29, and at weekly intervals thereafter the cultures were cut as follows: Group 1 was defoliated as close to the sand level as possible; group 2 was cut back to 1 inch above the sand level; group 3 to 3 inches; group 4 to 6 inches; and group 5 to 8 inches above the sand level. Green and dry weight determinations of recovery growth above these levels were made on each individual culture for each clipping date. In cases where this "recovery" growth was very small, the clippings from the six replications of a given group were weighed as one. After cutting from September to February 1, two cultures from the close cutting treatments, both plus and minus nitrogen, were covered to shut out all light and prevent photosynthetic activity.

On April 5, when the experiment was concluded, the sand was carefully washed from the roots and rhizomes of all the cultures which were alive The rhizomes, roots, and tops were separated and the green and oven-dry weight for each determined. At the close of the experiment three plus and three minus nitrogen cultures which had not been cut throughout the experiment were washed out and weighed likewise and served as final checks.

The root and rhizome systems of representative cultures of the various cutting treatments both plus and minus nitrogen were examined at frequent intervals. This examination was accomplished by lifting the cultures out of the pot by the leaves or by tipping the pots. This method left the sand intact around the roots and rhizomes and facilitated replacement of the culture without undue disturbance.

On April 5, photographs were taken of a representative culture from each cutting treatment, both plus and minus nitrogen and both before and after cultures were washed out.

DATA

When the cutting treatments were initiated on October 29, the plus nitrogen plants had a vigorous top, rhizome, and root growth. The leaves were dark green in color and tended to droop over the edges of the pot. The minus nitrogen plants were very similar to the plus nitrogen plants in rhizome and root development but had less top growth. In contrast with the leaves on the plus nitrogen plants, those of the minus nitrogen plants were lighter green in color, stiff and upright. This contrast in leaf character between the plus and minus nitrogen plants became more and more pronounced as the experiment progressed. This was particularly true of those not cut at all. This difference is shown in Figs. 1 and 2.

The average production of dry weights of clippings for all cutting treatments is shown in Table 1. The data show that through the first and second four-week periods of cutting the plus nitrogen close-cutting cultures made more recovery growth each week than any other cutting treatment After the second four-week period, the plus

nitrogen 6-inch cutting made on the average the most recovery growth. The 1- and 3-inch cutting treatments produced more recovery growth than did close cutting after the fourth four-week period.

In the plus nitrogen cultures the greatest total dry weight of clippings removed was made by the 6-inch cutting It was, however, only slightly greater than that made by the plus nitrogen close cut-

FIG. 1 Plus nitrogen quack grass cultures This photograph was taken April 5, one week after cutting From left to right a representative culture from each cutting treatment is shown as follows Completely defoliated cut to 1 3 6 and 8 inches once a week for 24 weeks and uncut or check

FIG. 2 —Minus nitrogen quack grass cultures This photograph was taken April 5 one week after cutting From left to right a representative culture from each cutting treatment is shown as follows Completely defoliated, cut to 1 3, 6, and 8 inches once a week for 24 weeks and uncut or check

ting treatment After removal of the original top growth the minus nitrogen close-cut cultures produced in the 23 weekly cuttings almost as much recovery growth as the plus nitrogen close-cutting treatment and about twice as much dry matter as any other cutting treatment in the minus nitrogen series

Through the twelfth week the recovery growth of the plus nitrogen close cutting treatment measured from 3 to 6 inches in height each week Up to the last few weeks the recovery growth of all other cultures receiving nitrogen was shorter than that of the cultures cut

close. In general, the recovery growth of the minus nitrogen close cutting was about an inch shorter than that of the plus nitrogen close cutting treatment, even though the dry weights were about the same.

TABLE 1.—*Dry weights in grams by four-week periods of clippings removed at weekly intervals from plus and minus nitrogen cultures.*

Weekly treatment	1st 4 weeks	2nd 4 weeks	3rd 4 weeks	4th 4 weeks	5th 4 weeks	6th 4 weeks	Total recovery growth
			Plus Nitrogen Cultures				
Complete removal of top growth (close cutting)	6.77	2.73	2.00	1.29	0.69	0.17	13.43
Cut back to 1 inch	4.11	1.55	1.76	1.28	1.77	1.32*	10.46
Cut back to 3 inches	4.18	2.03	1.34	1.03	1.15	2.33*	11.50
Cut back to 6 inches	2.64	1.33	2.91	1.67	2.68	4.01*	14.24
Cut back to 8 inches	1.58	0.34	0.95	0.23	1.01	1.13*	5.24
			Minus Nitrogen Cultures				
Complete removal of top growth (close cutting)	5.21	2.36	1.28	1.01	1.31	1.15*	12.03
Cut back to 1 inch	1.82	0.85	1.02	0.69	1.04	0.89*	6.09
Cut back to 3 inches	2.38	0.69	0.88	0.72	0.73	0.61*	5.84
Cut back to 6 inches	1.38	0.03	0.32	0.16	—	0.31*	1.89
Cut back to 8 inches	1.14	0.04	—	—	—	—	1.18

*Four-thirds of last 3 weeks growth.

As the experiment progressed, the leaves produced by the plus nitrogen close cutting treatment became narrower and paler in color. This tendency was also apparent in the minus nitrogen close cutting treatment but was at no time so pronounced. The leaf color of the other plus nitrogen plants tended to vary somewhat with the amount of sunlight. During a prolonged period of very low sunlight the plants became a paler green and as the sunlight increased, the deep green color returned. The minus nitrogen plants stayed a pale green color throughout the experiment.

Only two cultures of the plus nitrogen close-cutting treatment had any green shoots on April 5. Of these two, one was covered on February 1 so as to prevent photosynthetic activity and the other was left uncovered throughout the experiment. In these, only two or three weak shoots per pot were visible. In this cutting treatment three cultures failed to produce new shoots on and after March 15, and one culture failed to produce new shoots on and after March 29. Since one of the cultures which was covered on February 1 was still producing shoots on March 29, it is seen that covering these cultures had no apparent effect in hastening the death of the plants. No difference in rhizome or root development could be noted in the minus nitrogen cultures which were covered on February 1 as compared to those left uncovered and all were still alive.

The various cutting treatments had a marked effect on the subterranean parts of the plus nitrogen plants in particular. These effects were first noticed in the close cutting treatment. Within two

weeks after cutting was started some of the rhizomes had started to die back from the tips. By the end of the sixth week many of the rhizomes had died back to the second or third node, the tips taking on a water-soaked appearance. In the plus nitrogen 1-inch cutting cultures, the rhizome tips had started to die back by the fifth week of cutting but in the 3-inch cutting this took place much later and only to a limited extent. About the fifth week of cutting, the rhizome tips started to die back in the minus nitrogen close cutting treatment, while in the 1-inch cutting this dying back was apparent somewhat later and only to a limited extent. No dying back was apparent in the minus nitrogen 3-inch cutting at any time during the course of the experiment.

In the close and 1-inch cutting groups of the plus nitrogen cultures a number of rhizome tips turned upward and produced green leaves upon emergence. Likewise, some of the lateral buds initiated shoots which, upon emergence, produced green leaves. There was a limited increase in the number of new culms during the first few weeks, but the number decreased steadily thereafter, especially in the close-cutting treatment. After a few weeks of cutting the shoots produced in the plus nitrogen close-cutting treatment were found entirely around the outer rim of sand in the pot. To a lesser extent this was also true in the cultures receiving nitrogen and cut to 1 or 3 inches. Plus nitrogen cultures cut at 6 and 8 inches thickened up throughout.

In the minus nitrogen cultures cut close, about one-half of the rhizome tips turned upward and only a few of the lateral buds initiated shoots. After a few cuttings the new shoots of the minus nitrogen close-cutting treatment were found mostly around the outer rim of sand in the pot. The rhizome weights in grams are presented in Table 2. Figs. 1 and 2 show the appearance and comparative abundance of rhizomes, roots, and tops of typical cultures from the various cutting treatments.

Where nitrogen was supplied and the plants were cut close once a week for 24 weeks, the rhizome weight was negligible. Only one piece of rhizome about 3 or 4 inches long was left in each of two of these cultures. Cultures receiving nitrogen cut to 1 inch lost in total rhizome weight when compared to the initial checks. In the culture cut to 3 inches there was a small loss in rhizome weight. The rhizome weight of the quack grass under the minus nitrogen close-cutting treatment about equaled that of the plus nitrogen 1-inch cutting, while the rhizome weight of the minus nitrogen 1-inch cutting approximated that of the plus nitrogen 3-inch cutting treatment.

Fig. 3 is a photograph (taken April 5) of frayed discolored rhizomes from a plus nitrogen close-cutting culture and healthy rhizomes from a plus nitrogen check culture.

By January 11, or after 12 weeks of cutting, the root systems of the plus nitrogen close-cutting series had started to disintegrate. Disintegration of the root system was virtually complete by the end of the fifteenth week of cutting. When the experiment was discontinued after 24 weekly clippings, the root systems of the plus nitrogen 1-inch cultures also were disintegrated completely and the roots of

FIG 3 —Healthy rhizomes from plus nitrogen check culture at left and dead rhizomes from plus nitrogen close cut culture at right

the cultures receiving nitrogen and cut at 3 inches were showing some decay

In all the cutting treatments of the minus nitrogen plants the roots were abundant at the close of the experiment The root weights of the close, 1- and 3-inch cutting treatments were less than that of the initial checks, but all of the roots were of good color and had every appearance of being functional (See Fig 2)

Data in Table 2 show that the average total plant weight in both the plus and minus nitrogen treatments in the close, 1-, and 3-inch cutting groups was less than that of the initial check There was very little difference in the average total plant weight of the 6- and 8-inch cutting groups and final

TABLE 2 —*Dry weight in grams of rhizomes roots, and tops from plants grown with and without nitrogen after 24 consecutive weeks of cutting Weights from initial and final uncut checks are included*

Treatment	Rhizomes	roots	Tops	Total
Plus Nitrogen Plants				
Complete removal of top growth (close cutting)	0 02	0 0	0 02	0 04
Cut back to 1 inch	12 8	0 8	6 8	20 4
Cut back to 3 inches	27 3	6 9	15 8	50 0
Cut back to 6 inches	52 3	18 1	33 1	103 4
Cut back to 8 inches	64 7	23 2	63 0	150 9
Initial check (plants harvested before cutting was begun)	34 4	27 8	36 7	98 9
Final check (plants left uncut and harvested at end of experiment	76 6	27 8	60 7	165 1
Minus Nitrogen Plants				
Complete removal of top growth (close cutting)	11 8	3 6	0 52	15 9
Cut back to 1 inch	27 0	6 2	3 7	36.9
Cut back to 3 inches	38 8	9 7	8 8	57 3
Cut back to 6 inches	63 4	22 9	22 3	108 6
Cut back to 8 inches	58 6	29 0	28 0	115 6
Initial check (plants harvested before cutting was begun)	33 0	14 9	27 8	75 7
Final check (plants left uncut and harvested at end of experiment	56 7	30 0	27 6	114 3

check of the minus nitrogen treatment. In the plus nitrogen cultures the total plant weight was greatest in final check cultures, less in 8- and 6-inch cutting treatments.

Rhizomes from cultures receiving nitrogen were much higher in nitrogen than rhizomes from cultures receiving no nitrogen, as shown in Table 3. In the plus nitrogen cultures, rhizomes from the 1-inch cutting treatment were highest in nitrogen. In minus nitrogen cultures, rhizomes from the close-cutting treatment were higher in nitrogen than those from any other cutting height and the final check. Rhizomes from the final checks in the plus nitrogen cultures were higher in nitrogen than the initial checks, while in the minus nitrogen cultures the opposite was true; here the initial checks were highest in nitrogen. The rhizomes lowest in percentage of nitrogen at the conclusion of the experiment were those from cultures where the rhizome weight had been maintained about constant.

TABLE 3.—*Percentage total nitrogen on dry basis in quack grass rhizomes from plus and minus nitrogen cultures subjected to various cutting treatments.*

Treatment	Total nitrogen (dry basis)*	
	Plus N cultures %	Minus N cultures %
Completely defoliated		1.05
Cut back to 1 inch	2.12	0.65
Cut back to 3 inches	1.69	0.64
Cut back to 6 inches	1.74	0.71
Cut back to 8 inches	1.76	0.75
Initial check	1.81	1.18
Final check	2.00	0.87

*Analyses for nitrogen were made by the Section of Agricultural Chemistry, Michigan State College, East Lansing, Mich.

DISCUSSION

This experiment indicates that quack grass is influenced markedly by differences in defoliation and application of nitrogen.

Plus nitrogen quack grass cultures which were completely defoliated once a week had very few living shoots remaining after 24 weeks. Conversely, plants completely defoliated once each week and receiving no nitrogen were still producing many shoots after an equal period of cutting. In the minus nitrogen cultures the rhizome and root weight was about one-third as great as that of the initial checks while under the same conditions plus nitrogen plants were dead. Cutting cultures to 1 inch once a week was very injurious to plus nitrogen plants but caused only small injury to minus nitrogen plants. When plants receiving a continuous nitrogen supply were cut back to 3 inches, a loss in weight of rhizomes, roots, and tops resulted when compared to the initial checks. In a comparable treatment of minus nitrogen plants, there was a slight gain in rhizome weight, some loss of root weight, and a large loss in top weight.

Applications of nitrogen stimulated a vegetative response, resulting in more top growth. When this top growth was repeatedly removed by complete defoliation, the plant drew on its organic reserves to produce

new leaves. This treatment resulted in carbohydrate starvation and death of the plants.

Quack grass cultures in these experiments, however, were very conservative in their response to complete defoliation and heavy nitrogen applications since plants receiving an abundance of nitrogen with little or no opportunity for carbohydrate synthesis survived up to 24 weeks.

A further effect of nitrogen applications and repeated defoliations was noted in the total average dry weights of cultures from the various cutting treatments. In the plus nitrogen series the total average dry weight of cultures in the 6-inch cutting treatment was nearly equal to that of the initial check. In this treatment, however, the average rhizome weight was about one-third greater than that of the initial checks. In the plus nitrogen 3-inch cutting treatment, the average rhizome weight was less than that of the initial check. Considering these facts, it seems probable that the balance between vegetativeness and carbohydrate storage, as indicated by rhizome response, was somewhere between the 3- and 6-inch cutting treatments. On the other hand, this balance in the minus nitrogen cultures was between the 1- and 3-inch cutting treatment. As will be noted, the rhizome weight of the initial checks was about midway between the rhizome weights of the 1- and 3-inch cutting treatments.

Cutting the tops of minus nitrogen plants at 6 inches allowed for approximately maximum development of total plant weight In plus nitrogen plants, however, maximum plant weight was produced in the uncut or final check plants.

In 24 defoliations, the plus nitrogen cultures cut at the 6-inch level produced but little more total dry matter than did the plus nitrogen close-cut cultures. The close-cut cultures were virtually killed by the end of 24 weeks but produced more recovery growth during the first part of this period than did the 6-inch cutting cultures.

A plus nitrogen quack grass culture given ample opportunity for photosynthesis tends to store organic food reserves rather than use all of the newly synthesized products in the production of new top growth.

In the minus nitrogen cultures, the amount of recovery growth produced by the close cutting treatment was almost twice that produced by the next highest or 1-inch cutting during the duration of the experiment. From this it would appear that to obtain maximum production of top growth under extreme minus nitrogen conditions, extreme defoliations would be necessary. Cultures under this cutting treatment lost about two-thirds of their total rhizome and root weight when compared to the initial checks.

Minus nitrogen plants grown with moderate defoliation tended to store carbohydrate reserves more readily than did plus nitrogen plants correspondingly defoliated. Productivity of new top growth diminished rapidly as the experiment progressed in all but the close cutting treatment in the minus nitrogen series.

The rhizomes of minus nitrogen plants increased in weight under a more severe cutting treatment than did plus nitrogen plants. Further, the production of new top growth at a 1-inch cutting or longer was

much smaller in minus nitrogen cultures than under similar cutting treatment of cultures receiving nitrogen. Nitrogen became the limiting factor in leaf production of the minus nitrogen cultures cut to 1 inch or longer. Under the close cutting treatment of the minus nitrogen series, it is probable that the plants were able to obtain enough nitrogen from the dying roots and rhizomes to produce the fairly high recovery growth.

In the close cutting treatments the dry weight of rhizomes at the beginning of the experiment was almost the same in both the plus and minus nitrogen quack grass cultures. The plus nitrogen cultures had produced a slightly higher recovery growth at the end of 24 weeks. However, at the conclusion of the experiment the plus nitrogen plants were nearly all dead while the minus nitrogen plants still had about one-third of the original dry weight of rhizomes left. This is evidence that low nitrogen plants utilize carbohydrate reserves at a slower rate and will eventually produce more top growth, provided cutting treatments are carried on over a sufficient period of time.

SUMMARY

1. After being defoliated completely once a week for 24 weeks, quack grass cultures receiving a continuous supply of nitrogen had very few functional shoots.

2. Cultures receiving no nitrogen and defoliated once a week for an equal period of time were still growing steadily.

3. Cutting cultures to 1 inch once a week was very injurious to plus nitrogen plants but caused only slight injury to minus nitrogen plants.

4. Plus nitrogen cultures cut to 3 inches lost in rhizome, root, and top weight. In minus nitrogen cultures receiving comparable defoliation the rhizome weight increased, there was some loss of root weight, and a large loss in top weight.

5. Minus nitrogen quack grass plants stored organic reserves in subterranean parts at a more severe cutting level than did plus nitrogen plants.

6. Plus nitrogen cultures completely defoliated once a week produced approximately as much recovery growth over a period of 24 weeks as did cultures cut back to 6 inches but at the expense of previously stored reserves.

7. Minus nitrogen cultures completely defoliated once a week produced only slightly less recovery growth than did plus nitrogen cultures receiving the same cutting treatment, and produced about twice as much as the next highest minus nitrogen cutting treatment.

8. Insofar as these greenhouse studies may be considered indicative of the growth habits of quack grass under field conditions, they indicate that the fertilization of quack grass should give an increase in top growth which could be used for hay or pasture and that subsequent control measures on quack grass thus fertilized should prove less difficult.

LITERATURE CITED

1. DEXTER, S. T. Response of quack grass to defoliation and fertilization. Plant Physiol., 11:843–851. 1936.
2. GRABER, L. F. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiol., 6:43–72. 1931.
3. GRABER, L. F., NELSON, N. T., LEUKEL, W. A., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial suba-ceous plants. Wis. Ag. Exp. Sta. Res. Bul. 80. 1927.
4. HARRISON, CARTER M. Effect of cutting and fertilizer applications on grass development. Plant Physiol. 6:669–684. 1931.
5. THOMAS, WALTER. Composition of current and previous season's branch growth in relation to vegetative and reproductive responses in *Pyrus Malus* L. Plant Physiol. 7:391 447. 1932.

NOTE

PRESERVING LONG-TIME EXPERIMENTS IN CEMENT FRAMES[1]

AGRICULTURAL experiment stations are continually faced with the problem of whether to continue certain long-established field plats or to make the areas available for what appears to be more pressing current problems. This is especially true with long-established soil fertility plats. When experiments have been continued over a period of 40 or 50 years, there is always great hesitancy about discontinuing them in favor of new projects The question usually arises whether or not one may be discarding valuable material on soil conditions that have been developed over this long period of years, and which might be of inestimable value in some future work. After all, a continuous history of 50 years on a given area cannot be accumulated in less time than that. Usually, however, the old experiments have to give way to new projects due to limits of funds and available space

At the Rhode Island Agricultural Experiment Station it was found a few years ago that so much of the total available area was being used for continuing long-established soil fertility and crop rotation plats that it was becoming increasingly difficult to find adequate space for new projects. Some of the rotation experiments were terminated, but many of the soil fertility plats were considered too valuable in accumulated history to be discontinued. The thought then occurred that it might be possible to preserve certain of these plats in miniature by using a fairly large sample of soil from each in small cement-bordered soil frames

Among the plats with a continuous history over a considerable period of years was a 30-year comparison of manure-alone versus chemicals-only for vegetable crops When the comparison was begun, this question seemed of much more importance than it does today. Although this would not be considered a practical problem at present, certain soil conditions have been produced in these plats that may serve a very useful purpose in future studies on soil organic matter. It seemed desirable to preserve an adequate sample of these plats, although it did not seem worth while to continue these on a field plat scale.

Other plats deemed worthy of perpetuating on a smaller scale were a 40-year comparison of several phosphorus carriers, a similar comparison of various amounts of potash and of nitrogen, a 35-year comparison of cover crops in continuous corn culture, and individual plats that had shown definite indications of deficiencies in either magnesium, manganese, phosphorus, potash, or nitrogen. The greater number of these plats are being continued, but the smaller plats are now established so there will not be as great hesitancy in discontinuing some of these should this become desirable.

[1]Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station, as Contribution No. 533. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1938.

A series of 36 cement soil frames was constructed in the fall of 1934 similar to those that have been in use at the Cornell experiment station for many years.[2] Each frame is 1/1000 acre in area. The soils from the various plats were thoroughly mixed and placed in the frames in two 8-inch layers. A general view of these frames is shown in Fig. 1 Both the upper 8-inch layer and the lower 8-inch (subsoil) layer were obtained from sampling the original plat in a number of places. It was felt that the soil sample was representative of the entire plat.

The fertilizer applications used on the original plats have been continued on the frames. With the exception of the continuous corn frames, where corn has been continuously grown, a crop of potatoes,

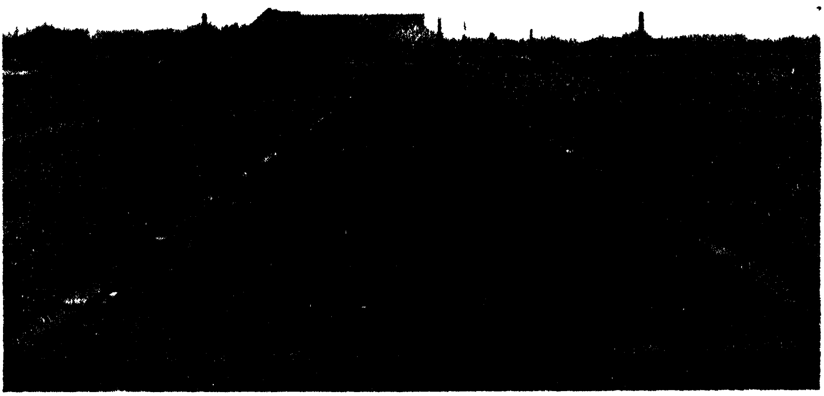

FIG. 1.- General view of cement frames at Rhode Island Agricultural Experiment Station.

one of corn, and one of soybeans have been grown since the frames were installed In the spring of 1938 the plats were seeded to a legume-grass mixture with oats as a nurse crop. The yields obtained have been compared with those obtained on the original plats during recent years and a high correlation is found. These soil-filled cement frames therefore seem to lend themselves very well to the purpose for which they are being used Although many of the original plats have now been discontinued, the Rhode Island Experiment Station still has a sufficient sample of the original, not only to continue obtaining similar information to that originally obtained, but also has a large enough sample on hand to use for other purposes such as chemical determinations.

These cement frames have been found particularly interesting to visitors at the experimental plats. It is possible to conduct a visitor or a small party to these frames and in a few minutes point out to them the symptoms of various soil deficiencies on growing crops, the effect of long-continued use of various fertilizers, and other experi-

[2]LYON, T. L., and LELAND, E. W. Artificial plats for field experiments. Jour. Amer. Soc. Agron., 18:596–602. 1926.

mental work. It is much more quickly accomplished and usually with more satisfaction than if a tour of the larger plats exhibiting similar conditions is made.

The method here described for continuing certain long-time experiments in miniature plats is recommended for consideration where problems of limited funds and space are confronted as was the case at the Rhode Island Experiment Station. —T. E. ODLAND and G. F. LEA, *Rhode Island Agricultural Experiment Station, Kingston, R. I.*

BOOK REVIEWS

THE STRUCTURE OF ECONOMIC PLANTS

Herman E. Hayward New York: The Macmillan Company. X+ 674 pages, illus. 1938. $4.90.

THIS book, long awaited and modest in price for the size and abundance of material which it contains, is an outgrowth of the course in plant anatomy given by the author at the University of Chicago. It attempts to bring together valuable anatomical work which has been done in the form of monographs on specific plants, many of them dealing with restricted phases of a particular plant as studies incidental to research in physiology, pathology, pharmacology, and other fields of plant science These have been combined so as to present a thorough and complete story about the following important economic plants: Corn, wheat, onion, hemp, beet, radish, alfalfa, pea, flax, cotton, celery, sweet potato, white potato, tomato, squash, and lettuce.

Although each plant is discussed in detail, a nice distinction in emphasis is made for each crop by discussing most fully the special features which make that crop of economic significance. For example, the discussion of hemp emphasizes the structure of the stem and devotes a section to pericyclic fibers, while the discussion of the beet emphasizes the fleshy axis, secondary thickening, and tertiary thickening.

The book is in two parts, Part I, of 109 pages, dealing with general plant anatomy, and Part II with particular plants. It is well illustrated with outline drawings and photographs and contains an adequate bibliography and a helpful glossary. The point of view throughout is that of developmental anatomy and as such will be found of special value because of its relation to studies of physiology and experimental morphology. It should find wide appeal. (H. B. T.)

COMMERCIAL FERTILIZERS, THEIR SOURCES AND USE

By Gilbeart H. Collings Philadelphia: P. Blakiston's Son and Co., Inc. Ed. 2. XVII+456 pages, illus. 1938. $4.00.

THIS is the second edition of this excellent book on commercial fertilizers. Like the former edition of 1934 it presents the most recent authentic information for anyone interested in growing larger yields of crops through the use of fertilizers, as well as being a guide for fertilizer manufacturers and a textbook for students of the subject.

The material is revised and brought up to date, a very essential requirement in this rapidly changing field, and the book is also enlarged by some 100 pages. New trends in fertilizer manufacture and use are gone into in some detail as well as new concepts of soil fertility and crop nutrition. Much new material is presented in the field of minor elements as well as on the problems of adjusting soil reaction and fertilizer practice to crop requirements.

The new volume contains a much enlarged bibliography of 385 titles and an author and subject index. Anyone who found the first edition useful will welcome this still more complete and comprehensive revision. (R. C. C.)

COTTON

By H. B. Brown, New York: McGraw-Hill Book Co., Inc. Ed. 2. XIII + 592 pages, illus. 1938. $5.00

ALTHOUGH synthetic fibers are making a strong bid for recognition, cotton is still the most important source of raw material in the textile world. How long this remains so depends upon the progress which will be made in the immediate future in cotton production and the use of the fiber. If the extensive program of cotton improvement in the United States is to go forward, more extensive and more thorough instruction must be given by our universities and colleges in the factors of production, particularly those affecting the quality of the fiber. Those who are responsible for this instruction, as well as the cotton grower and breeder, will welcome this second edition of H. B. Brown's "Cotton", the most comprehensive text dealing with this crop

In general, it may be said that the entire book has been brought up to date Although no new chapters have been added, the 25 chapters of the first edition have been revised to the limit of the new knowledge made available by recent cotton research, increasing the total number of pages from 517 to 592.

From the reviewer's point of view, the most urgent problems in the entire field of cotton investigation are those relating to the physiology of the plant, properties of the raw fibers, and the breeding of improved varieties. In the chapter on the physiology of the plant, new discussions have been added regarding the relation of water supply to development, temperature to yields, varietal differences with regard to absorption of soil solutions, the various factors affecting earliness, and others. Under fibers the new work on the development of the cotton fiber is reported. Also the difficult process of separating and measuring the different class lengths of the fibers in a ginned sample is described as well as the Suter-Webb cotton fiber sorter by which the fibers are separated into their various class lengths.

A valuable addition to this discussion, particularly for the breeder, would have been a description of some of the methods developed recently for length determinations of lint taken directly from the seed by length classes. In the chapter on breeding, asexual reproduction, defloration, acclimatization, and the delinting of planting seed are among the important items discussed. New knowledge has also been added to the chapter on fertilizers and rotations, diseases, and insects. In the chapter on spinning qualities, much information is given concerning the improvement of the quality of the fiber by means of better ginning and handling and by breeding and introducing improved varieties.

Ninety-five new references have been added. As the book now stands, it is indispensable as a text for students, a valuable help to

the investigator, and the best source of information for those who have a general interest in cotton. (W. E. B.)

AGRONOMIC AFFAIRS

THE HENRY STRONG DENISON GRADUATE FELLOWSHIPS IN AGRICULTURE AT CORNELL UNIVERSITY

THE BOARD OF TRUSTEES of Cornell University has announced the establishment of the Henry Strong Denison Graduate Fellowships in Agriculture, in memory of Henry Strong Denison, a graduate of Cornell University in the class of 1905. These fellowships were created by a gift from the Henry Strong Denison Medical Foundation, Inc., founded by Mrs. Ella S. Denison.

Three fellowships with an annual stipend of $1,000 each will be awarded in the fields of the plant sciences, animal sciences, and social sciences and agricultural engineering, for the purpose of encouraging young graduate students "who are especially gifted and qualified to carry on research work in the science of agriculture."

In awarding the fellowships, preference will be given to those applicants who expect to complete the requirements for the Ph.D. degree and who appear most promising from the standpoint of ability to conduct research. Blank forms of application may be obtained from the Dean of the Graduate School, Cornell University, Ithaca, N. Y., and all applications must be filed in the Office of the Graduate School before March 1, 1939.

THE NATURALIST'S DIRECTORY

THIS reference volume contains the names, addresses, and special subjects of study of professional and amateur naturalists in North and South America and other countries. The 1938 edition has just been published and is obtainable for $3.00, postpaid, from the Naturalist's Directory, Salem, Mass.

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ALFALFA NURSERY TECHNIC[1]

H M TYSDAL AND T. A. KIESSELBACH[2]

WITH the development of numerous new strains of alfalfa requiring testing in various improvement programs, the results of an alfalfa nursery method study at the Nebraska Agricultural Experiment Station would seem of interest. The chief objective of these investigations has been to determine whether the yields and other data obtained from small nursery plats with low seed requirements are comparable with those from ordinarily accepted field plats

Variations in nursery technic were studied with respect to such factors as number of rows per plat, distance between rows, alley space between plats, removal of border rows at harvest, interplat varietal competition, spacing of plants within the row, planting equal amounts of seed per row versus equal amounts per acre for the different row spacings, and plat distribution The tests were made through comparable, adjacent plantings of two varieties, Hardistan and Ladak, which differ in growth habits and productivity. The relative yields of these two varieties under the various modes of testing are reported.

MANNER OF LAYING OUT THE TEST

The general planting plan of one complete replication, showing the plat distribution, number of rows per plat, and the row-spacing, is illustrated in Fig. 1. The plats were planted in eight beds of two complete replications each. Within a replication, similar types of plats of the two varieties were always placed adjacent to enable a direct study of differential varietal responses in the various plat types. Adjacent unlike plats were separated by suitable guard rows in order to provide the specific conditions required of the tests. Since there were eight beds and seven main types of nursery plats under comparison, the latter were so distributed in the beds that the same type of plat did not fall in the same strip or column more than once (with one exception), thus resembling in this respect a Latin square arrangement.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 217. Received for publication November 10, 1938.

[2]Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Agronomist, Department of Agronomy, Nebraska Agricultural Experiment Station, respectively.

The 1/80-acre field plats adjacent to the nursery plats were sown with a standard 7-foot alfalfa drill which spaced the rows 4 inches apart. The rows of the nursery plats, sown with a 1-row Columbia garden drill, were all 16 feet in length but differed as to number and spacing. Variations in number of rows were 1, 3, 4, and 8 rows per plat, while the row spacings under comparison were 7, 18, and 24 inches. The locations of the two varieties, Hardistan and Ladak, are indicated in the diagram by solid and broken lines, respectively. The guard rows placed between the different spacings are also shown. These guard rows do not enter into any of the calculations on varietal yields, but are used to show the effects of row-spacing and thickness of stand on interplat competition. A total of 16 replications of each type of plat was planted.

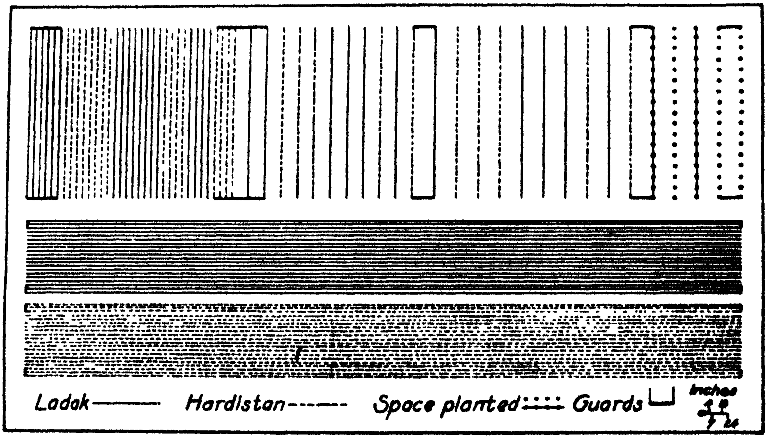

FIG. 1.—Planting plan of one complete replication of the alfalfa method study nursery. The nursery rows are represented in the upper part of the figure, while the two field plats are below. The entire distribution is drawn to scale; thus the spacings between rows are shown by the distance between the lines. The guards inserted between unlike spacings are shown by joining the ends of the guard rows with a heavy solid line. The two varieties, Ladak and Hardistan, are represented by solid and broken lines, respectively.

The various row spacings in nursery plats were compared with two rates of seeding, equal rates per row and equal rates per acre. While all the 7-inch rows were sown with 1.46 grams of seed per row or at the rate of 15 pounds per acre, only half of the 18- and 24-inch rows were seeded at this same rate per row (1.46 grams), which amounted to approximately 6 and 4 pounds per acre, respectively. The other eight replications of these two wider spacings were sown at the respective rates of 3.7 grams and 5.0 grams per row in order to provide equal rates per acre (15 pounds) corresponding with the 7-inch rows. The field plats also were planted at the rate of 15 pounds per acre.

The effect of additional alley space between nursery blocks was studied by increasing the distance between border rows of the 7-inch blocks to 12 inches in half the replications. In the other eight replications this distance was 7 inches, which provided no extra alley space.

All plats were solid-drilled with the exception of single, well-guarded rows spaced 24 inches apart which were sown lightly and thinned in the seedling stage so that the plants were spaced 12 inches apart in the row. These will be called the

"space-planted" in contrast with the "solid-drilled" rows. The entire test was sown in the spring of 1933 after fallow for one year.

NURSERY AND FIELD PLATS COMPARED

The plats were not cut in 1934, partly because of the drought but chiefly because it was desired to allow the plants to become thoroughly established before yields were taken. Three cuttings were obtained from all plats in 1935, but because of unusually severe drought only one cutting materialized in 1936 and one in 1937. In field plats in the three successive years, Hardistan yielded 5,981, 1,616, and 1,180 pounds of hay (15% moisture content) per acre, compared with 7,061, 2,037, and 1,520 pounds for Ladak The superiority of Ladak amounted to 18, 26, and 29% in the different years. These annual yields from the field plats, together with those from the various kinds of nursery plats, are reported in Table 1. For the purpose of these comparisons the yields are calculated for the interior rows only in case of the multiple-row plats in order to avoid possible interplat competition effects as far as possible Thus, the yields of 8-, 4-, and 3-row nursery plats are based on the 4, 2, and 1 middle rows, respectively, while a 4.5-foot swath was harvested from the middle of the 7-foot field plats

In all types of plats the Ladak outyielded the Hardistan every year by a large and significant margin, though varying in amount For the different types of plats, the following ratios for the 3-year average yields of Ladak to Hardistan, expressed in per cent, are found: Field plats, 4-inch spacing, 121; 8-row, 7-inch spacing, 127; 4-row, 7-inch spacing, 123; 3-row, 18-inch spacing, 125; 1-row, 18-inch spacing, 118; 3-row, 24-inch spacing, 125; 1-row, 24-inch spacing, 121; and 1-row, 24-inch spacing, space-planted, 128 Corresponding ratios for the favorable year, 1935, were 118, 127, 123, 125, 119, 123, 118, and 121.

The extreme departure of the 3-year ratios of any of the four types of multiple-row nursery plats from that of the field plats was 6%. In single-row plats spaced 24 inches apart, the relative yields were the same as in field plats, while in the single rows spaced 18 inches the departure was 3%. In the space-planted rows the superiority of Ladak was 7% greater than in the field plats.

The statistical significance of these differences was determined by applying the analysis of variance to the yields of the middle rows of the multiple-row nursery plats and the field plats. The 1935, 1936, and 1937 yields of the 16 replicates of all types of plats shown in Table 1 having more than one row per plat were used. Thus five types of plats were compared and it was found that there was no significant interaction[3] of the varieties on the different plats studied, the

[3]Throughout this paper the term "interaction" is used in the following sense: Of two varieties A and B, suppose A yields 10% more than B under one set of conditions and only 5% more than B under a different set of conditions. This differential response is called "interaction" and can be studied by separating the different elements contributing to variation, as shown in Table 2. For example, in the following studies, Hardistan yielded relatively more compared with Ladak under certain conditions, chiefly due to competition effects. One of the problems is to determine if these differences in relative yields are statistically significant. In this paper significance is arbitrarily placed at the commonly accepted odds of 19 to 1.

TABLE 1.—*Effect of row and plant spacing upon the yield of two varieties of alfalfa.*

Kind of plat	Space between rows, in.	Spacing of plants	Rows per plat	Yield of forage per acre (15% moisture)*: Actual, lbs. Hardistan	Actual, lbs. Ladak	Relative, % Hardistan	Relative, % Ladak	Ratio Ladak to Hardistan yield, %
				1935				
Field	4	Solid	20	5,981	7,061	100	100	118
Nursery	7	Solid	8	7,206	9,118	120	129	127
Nursery	7	Solid	4	7,563	9,315	126	132	123
Nursery	18	Solid	3	7,292	9,113	122	129	125
Nursery	18	Solid	1	7,365	8,729	123	124	119
Nursery	24	Solid	3	6,871	8,466	115	120	123
Nursery	24	Solid	1	6,938	8,203	116	116	118
Nursery	24	12 inches	1	4,410	5,347	74	76	121
				1936				
Field	4	Solid	20	1,616	2,037	100	100	126
Nursery	7	Solid	8	1,822	2,278	113	112	125
Nursery	7	Solid	4	1,843	2,279	114	112	124
Nursery	18	Solid	3	1,737	2,157	107	106	124
Nursery	18	Solid	1	1,759	2,037	109	100	116
Nursery	24	Solid	3	1,645	2,109	102	104	128
Nursery	24	Solid	1	1,630	2,051	101	101	126
Nursery	24	12 inches	1	1,707	2,345	106	115	137
				1937				
Field	4	Solid	20	1,180	1,520	100	100	129
Nursery	7	Solid	8	1,196	1,548	101	102	129
Nursery	7	Solid	4	1,402	1,659	119	109	118
Nursery	18	Solid	3	1,294	1,672	110	110	129
Nursery	18	Solid	1	1,407	1,624	119	107	115
Nursery	24	Solid	3	1,192	1,525	101	100	128
Nursery	24	Solid	1	1,163	1,533	99	101	132
Nursery	24	12 inches	1	1,391	1,914	118	126	138
				Averages for 3 Years				
Field	4	Solid	20	2,926	3,539	100	100	121
Nursery	7	Solid	8	3,408	4,315	116	122	127
Nursery	7	Solid	4	3,603	4,418	123	125	123
Nursery	18	Solid	3	3,441	4,314	118	122	125
Nursery	18	Solid	1	3,510	4,130	120	117	118
Nursery	24	Solid	3	3,236	4,033	111	114	125
Nursery	24	Solid	1	3,244	3,929	111	111	121
Nursery	24	12 inches	1	2,503	3,202	86	90	128

*In the case of multiple-row plats, the yields are based on the interior rows only.

$\frac{\text{Mean square}}{\text{Mean square error}}$ equalling 1.24, while the 5% F value was 2.44 and the 1% F value, 3.46. Details of the analysis are shown in Table 2. A similar analysis made for the solid-drilled and space-planted single-row plats comparing them in each case with the field plats again gave no significant interaction between varieties and type of plat.

From these analyses the conclusion may be drawn that the several types of nursery plats gave essentially the same *relative* yields of the two varieties as did the field plats.

TABLE 2.—*Variance analysis of the yields from the interior rows of field plats and four types of multiple-row nursery plats, namely, 8-row, 7-inch spacing, 4-row, 7-inch spacing; 3-row, 18-inch spacing, and 3-row, 24-inch spacing, 16 replications, average of 1935, 1936, and 1937 crops.*

Source of variation	Degrees of freedom	Sum of squares	Mean square	F value*
Varieties	1	25,525,684	25,525,684	—
Replications	15	12,740,405	849,360	—
Type of plat	4	12,198,312	3,049,578	—
Interaction.				
Variety × type of plat	4	449,911	112,478	1.24
Error: Variety × replication	15			
Error: Replication × type of plat	60 (Total 135)	12,244,196	90,698	—
Error: Variety × rep. × type of plat	60			
Total	159	63,158,508		

*The F values for the 5 and 1% points, respectively, are 2.44 and 3.46 as obtained from Snedecor, G. W. Calculation and Interpretation of Analysis of Variance and Covariance. Ames, Iowa: Collegiate Press, Inc. 1934. (Pages 88–91.)

INTERPLAT COMPETITION AND ALLEY SPACE EFFECTS

Since the two varieties, Hardistan and Ladak, were planted alternately in both single- and multiple-row plats, and since all rows were harvested individually for yield determination, it was possible to calculate the extent to which yields were modified by interplat competition and alley space. This was done through a comparison of yields based on the interior rows, which are regarded as relatively free from interplat competition and other marginal effects. The data are reported in Table 3. The results for 1935 only are presented. The indications of that year were generally confirmed both in 1936 and 1937. The plants had become well established by 1935.

MULTIPLE-ROW PLATS

It will be recalled that half the plats with 7-inch row spacing were separated by only 7 inches between border rows (alley space), while the other half (eight replications) had a corresponding separation of 12 inches. The comparative effects of these two different spacings between plats is brought out strikingly in Table 3. Not only were the yields of the border rows materially higher for the 12-inch alley space, but the relative yield of the Ladak was greatly increased in the border rows. At the 7-inch spacing between 8-row plats, the border rows (rows 1 and 8) of Ladak yielded 108% of Hardistan, whereas in the middle rows it yielded 127% of Hardistan. Similarly, in the 4-row plats Ladak yielded 106% in the border rows compared to 126% in the interior rows. With a 12-inch alley space, the border rows (rows 1 and 8) of the Ladak in 8-row plats yielded 129% of the Hardistan, while in the 4 middle rows it yielded 126% of Hardistan. In the

border rows of the 4-row plats separated by a 12-inch alley space, the Ladak yielded 115% of Hardistan compared with 121% in the two middle rows.

TABLE 3.— *Relative yields of two alfalfa varieties differing in growth habits when compared in alternating nursery plats differing as to row number, plant and row spacing, and portion harvested, 1935.*

Portion of plat considered	Yield of forage per acre (15% moisture)				Ratio Ladak to Hardistan yield, %
	Actual, lbs.		Relative, %*		
	Hardistan	Ladak	Hardistan	Ladak	
7-inch Spacing Between Rows					
8-row plats, average for plats having 7 and 12 inches between border rows of adjacent plats:					
4 middle rows	7,206	9,118	100	100	127
Rows 2 and 7	7,622	9,304	106	102	122
Rows 1 and 8†	8,800	10,537	122	116	120
Entire plat	7,593	9,434	105	103	124
8-row plats, 7 inches between border rows:					
4 middle rows	7,362	9,333	102	102	127
Rows 2 and 7	7,457	9,111	103	100	122
Rows 1 and 8	7,961	8,622	110	95	108
Entire plat	7,429	9,100	103	100	122
8-row plats, 12 inches between border rows:					
4 middle rows	7,049	8,903	98	98	126
Rows 2 and 7	7,786	9,496	108	104	122
Rows 1 and 8†	9,638	12,389	134	136	129
Entire plat	7,757	9,767	108	107	126
4-row plats, 7 inches between border rows:					
2 middle rows	7,380	9,293	102	102	126
Rows 1 and 4	8,026	8,504	111	93	106
Entire plat	7,703	8,899	107	98	116
4-row plats, 12 inches between border rows:					
2 middle rows	7,745	9,337	107	102	121
Rows 1 and 4†	9,900	11,380	137	125	115
Entire plat	8,823	10,359	122	114	117
4-row plats, average for plats having 7 and 12 inches between border rows:					
2 middle rows	7,563	9,315	105	102	123
Rows 1 and 4†	8,963	9,942	124	109	111
Entire plat	8,263	9,629	115	106	117

*The relative yields are based on the actual yields from the four middle rows of all 8-row plats in which the rows were spaced 7 inches apart.

†The actual area occupied by these border rows spaced 12 inches apart is 36% greater than that of the interior rows. The acre yield as indicated, however, is calculated on the same area basis as interior rows.

TABLE 3.—*Concluded.*

Portion of plat considered	Yield of forage per acre (15% moisture)				Ratio Ladak to Hardistan yield, %
	Actual, lbs		Relative %*		
	Hardistan	Ladak	Hardistan	Ladak	
18 inch Spacing Between Rows					
3-row plats:					
Middle row	7,292	9,113	101	100	125
Rows 1 and 3	7 289	8,921	101	98	122
Entire plat	7,339	8,985	102	99	122
1-row plats:					
Single row	7 365	8,729	102	96	119
24-inch Spacing Between Rows					
3-row plats:					
Middle rows	6,871	8,466	95	93	123
Rows 1 and 3	6 944	8 380	96	92	121
Entire plat	6,914	8,418	96	92	122
1-row plats:					
Single row	6,938	8,203	96	90	118
1-row plats, space planted, 12 inches between plants					
Single row	4,410	5,347	61	59	121

*The relative yields are based on the actual yields from the four middle rows of all 8-row plats in which the rows were spaced 7 inches apart

With such striking differential response of varieties to border competition when grown in multiple-row plats with rows spaced as close as 7 inches, it would seem highly important to base varietal yields in such plats on the interior rows only. By widening the alley space between adjacent plats of this type from 7 to 12 inches this differential interplat competition was largely eliminated and was not found statistically significant.

Of further interest is the fact that in closely-spaced rows the higher-yielding variety, Ladak, is depressed by competition with the lower-yielding variety, Hardistan. This may perhaps be partly explained by the fact that Hardistan generally recovers more quickly after cutting than Ladak and also has a tendency to grow slightly taller in all but the first cutting. As an average of from 8 to 15 readings the following heights have been recorded for Ladak and Hardistan at the time of cutting: 1st cutting, Ladak 18.80 inches, Hardistan 18.66 inches; 2nd cutting, Ladak 17.25, Hardistan 20.91; 3rd cutting, Ladak 10.92, Hardistan 15.53 inches.

In the case of multiple-row plats with widely spaced rows, the degree of interplat varietal competition was very slight and not statistically significant. With 18-inch row spacing, Ladak yielded 125% of Hardistan in the middle rows and 122% in the border rows.

With 24-inch spacing, Ladak yielded 123% in the middle rows and 121% in the border rows. Such small border competition effects might perhaps be ignored in most varietal comparisons made in this type of plat.

SINGLE-ROW PLATS

The data from alternating single-row plats of Hardistan and Ladak alfalfa spaced 18 and 24 inches apart are contrasted (Tables 1 and 3) with the middle rows of corresponding 3-row plats.

The superiority of Ladak in 18- and 24-inch, single-row plats was 7% and 4% less, respectively, as a 3-year average than in the middle rows of corresponding 3-row plats. This suggests an appreciable degree of interplat competition between the single 18-inch rows but less for the 24-inch spacing. For the favorable year 1935, the superiority of Ladak was 6 and 5% less, respectively, in the single 18- and 24-inch rows than in the interior rows of corresponding 3-row plats, suggesting some interplat competition for single rows of both spacings, though the effects were not statistically significant.

STATISTICAL SIGNIFICANCE OF COMPETITION EFFECTS

The variance analysis, similar to that presented in Table 2, shows the interaction to be significant between the border rows and middle rows of the 8-row and 4-row plats that were separated by a 7-inch alley space, the significance being above the 1% point in both cases. The interaction in the same types of plats with 12 inches alley space was not significant. In other words, there was a great deal of varietal competition across a narrow 7-inch alley space, resulting in a differential yield of the two varieties but not sufficient competition with the wider, 12-inch alley to change significantly their relative yields.

In calculating the interaction of the 18-inch spacing the 3-row and 1-row plats were considered separately. The middle rows of the 3-row blocks were compared with the border rows and also with the alternating single-row plats. Neither interaction was statistically significant.

The plats with rows spaced 24 inches apart were analyzed in a similar manner, and again, neither the border rows of the 3-row plat nor the single alternate rows differed significantly from the center row of the 3-row plat.

These analyses indicate that under the conditions of this experiment there was significant varietal competition between the border rows when spaced 7 inches apart. When the border rows were spaced 12 inches, or more, there was no statistically significant modification of comparative varietal yields through interplat competition.

EFFECT OF ALLEY SPACE ON YIELD OF NURSERY PLATS

That the yield of alfalfa responds to variations in the width of alley space (distance between border rows) separating nursery plats is shown in Table 3 for those plats in which the rows were 7 inches apart. As an average for two varieties, in 8-row plats, the border rows yielded the same as the four middle rows when the alley space was 7 inches, whereas they yielded 36% more when the alley space was 12

inches. Since the area occupied by the row increased 35.7%, the increase in yield corresponded very closely with the increase in area. Rows 2 and 7 were also affected by the competition, yielding 7% more than the four middle rows. This border effect caused the entire plat to yield 9% more in response to 5 inches of added alley space which was an increase of 9% in plat area

In a similar test with 4-row plats, the border rows yielded the same as the middle rows when the alley space was 7 inches, while they yielded 31% more when the alley space was widened to 12 inches. This border effect caused the entire plat to yield 14% more in response to the 5 inches wider alley space which was an increase of 18% in plat area. Since the border rows of plats respond favorably to increased alley space, such additional space should preferably be included in the area of the plats when acre yields are calculated

SPACE-PLANTED ROWS

Although the actual acre yield was far lower in 1935 for the space-planted rows, the relative yields of the two varieties tested were nearly the same as for the close-drilled field plats In the two succeeding years, when the plants had become better established and the crop suffered more from moisture deficiency, the space-planted rows actually outyielded the field plats and the superiority of Ladak was somewhat greater than for any other type of field or nursery plat. This advantage of Ladak during the last two years probably may be accounted for by a more rapid crown growth (Table 6) which would enable it to occupy the land more completely In general, space-planted nursery plats would seem somewhat less exact for varietal yield determinations than are solid-drilled plats.

MODIFICATION OF PLAT YIELDS BY ADJACENT UNLIKE PLATS

As a result of having determined the yield of the various guard rows, several illustrations are available of the striking border-row response to dissimilar adjacent plats differing as to spacing of rows or plants. The data are suggestive of the magnitude of the error that may occur if a hardy strain is growing in a nursery plat adjacent to one which has a very poor stand due to winterkilling or other causes. The yields of interior plat rows, which are relatively free from unlike competition, and of corresponding border rows are reported in Table 4.

The first comparison in the table is one of the most interesting. A solid-drilled block with 7-inch row spacing was separated by a 7-inch alley space from a space-planted block with rows 24 inches apart. Of the adjacent border rows when compared with their respective types of interior rows, the solid-drilled row gave an excess yield of 74% because of reduced competition on one side, whereas the space-planted row was depressed 63% in yield because of increased competition.

The other comparison in Table 4 is between two rows spaced 18 inches apart, one of which was the last row of a multiple-row plat with 7 inches between its rows, while the other was the first row of a multiple-row plat with 18 inches between its rows. The row with 7-

inch spacing on one side and 18 inches on the other exceeded the yield of the interior rows of the 7-inch spacing by 87%. On the other hand, the row with 18-inch spacing on one side and the plat having 7-inch spacing at a distance of 18 inches on the other was reduced 7% in yield compared to the interior row of 18-inch spacing.

TABLE 4.—*Border competition between nursery plats differing as to spacing of rows or plants.**

Description of competing plats				Yield of forage per acre (15% moisture)					
Plats on which yields are reported		Adjacent modifying plats		Actual lbs			Relative, %		
Space between rows, in	Type of planting	Space between rows, in	Type of planting	First border row	Second border row	Interior row	First border row	Second border row	Interior row
Adjacent Plats Separated by 7-inch Alley Space									
7	Solid	24	Spaced	15,840	10,361	9,118	174	114	100
24	Spaced	7	Solid	1,616	3,802	4,410	37	86	100
Adjacent Plats Separated by 18-inch Alley Space									
7	Solid	18	Solid	13,455	8,257	7,206	187	115	100
18	Solid	7	Solid	8,503	8,827	9,113	93	97	100

*The two varieties Ladak and Hardistan, were adjacent in this test, but the varietal competition played a very minor rôle being less than 10% in the 7 inch spacing and not greater than 2% in the 18 inch spacing

Similar effects may be illustrated as follows from data not shown in the table: When two rows were spaced 24 inches apart, one of which was the last of an 18-inch spacing and the other was the first of a 24-inch spacing, the yield of the former was increased 9% and that of the latter was reduced 6% as compared with comparable interior rows Wherever a slight opportunity is afforded for expansion, the plants are quick to take advantage of it. Perhaps this is particularly true where there is relatively severe competition for soil moisture.

The data also give some indication as to how many marginal rows of a plat are affected by border competition. In the case of the second border row in the solid-drilled 7-inch spacing, the excess yield resulting from lowered competition with adjacent space-planted alfalfa amounted to only 14%, compared with 74% for the outside border row. Yields obtained in 1937 on the third and fourth rows from the border indicate little carryover of the effect into the third row, which was only a total of 14 inches from the border. It seems evident that great care must be exercised in taking yields from rows which are apt to be either at an advantage or a disadvantage with respect to spacing of rows or density of stand.

RATE OF SEEDING NURSERY PLATS

As previously indicated, half of the plats with 18- and 24-inch row spacing were sown to the same amount of seed per row as the 7-inch rows, while the other half were sown at equal amounts of seed per acre. The amounts of seed per acre were approximately 4, 6, and 15 pounds for the 24-, 18-, and 7-inch rows when sown at equal amounts per row, whereas 15 pounds per acre was the uniform rate when all spacings were sown at equal rates per acre. The yields from these tests are given in Table 5.

TABLE 5.—*Comparative yields in 1935 of Hardistan and Ladak alfalfa when seeded at equal rates per row versus equal rates per acre in nursery test plats differing as to row spacing, yield based on the interior rows relatively free from border competition.*

Space between rows, in	Rows per plat	No. interior rows harvested	Yield of forage per acre (15% moisture) when equal amounts of seed are sown per: Row — Hardistan lbs	Row — Ladak lbs	Row — Ratio Ladak to Hardistan %	Acre — Hardistan, lbs	Acre — Ladak lbs	Acre — Ratio Ladak to Hardistan, %	Ratio yield row basis to acre basis: Hardistan, %	Ladak, %
7	8	4	7,206	9 118	127	7 206	9,118	127	100	100
18	3	1	7.493	9 588	128	7 089	8 638	122	106	111
24	3	1	7 041	8,754	124	6 701	8 179	122	105	107

Increasing the amount of seed per row in the two wider spacings in order to provide equal seeding rates per acre proved a slight disadvantage for both varieties as reflected by somewhat lower yields per acre. This reduction ranged from 5 to 11%.

As to effect on the relative yield of the two varieties, Ladak yielded 27, 28, and 24% more than Hardistan in the 7-, 18-, and 24-inch spacing, respectively, when seeded at equal rates per row, compared with 27, 22, and 22% superiority when seeded at equal rates per acre. Assuming that the relative yields of the two varieties in the 7-inch spacing most nearly represent true farm performance, the departure was only 1 and 3%, respectively, in the 18- and 24-inch spacings when planted at equal rates per row and 5% for both spacings when sown at equal rates per acre.

It is concluded that there may be considerable latitude in the amount of seed sown in rows spaced various distances apart. When the spacing between rows materially exceeds 7 inches, however, it seems preferable to approximate the 1.5 grams of seed per 16-foot row as required in 7-inch spacing planted at 15 pounds per acre.

RATE OF SEEDING IN RELATION TO SUBSEQUENT STAND AND CROWN SPREAD

The plats concerned in these method studies were plowed in March, 1938, and this afforded an opportunity to make counts on the actual

number of plants surviving per row. The crown spread at the surface of the ground was also determined for 10 or more rows of both varieties in each type of plat

Table 6 is a summary of the counts and measurements, each figure for the number of plants per acre being an average of at least eight counts of the number of roots made at the edge or bottom of the furrow. This method of counting has been found much more accurate than trying to count the number of plants at the surface of the ground.

TABLE 6.—*Number of plants per row and per acre and crown spread at surface of ground in 1937 as related to the rate of seeding in different types of plats in 1933*

Kind of plat	Space between rows, in.	Rate of seeding: Per acre, lb	Rate of seeding: Per 16-ft row, grams	Number of plants per acre: Hardistan	Number of plants per acre: Ladak	Crown spread: Hardistan in	Crown spread: Ladak in	Crown spread: Ratio Ladak to Hardistan, %
Field	4	15	0.84	500,300	504 100	2 41	2 57	106 6
8-row	7	15	1 46	686,100	658,100	3 00	3 29	109 7
3-row	18	15	3 70	473,700	446,500	4 61	4 56	97 6
3-row	18	6	1.46	377,500	361,200	4 75	4 97	104 6
3-row	24	15	5.00	296,800	349,800	4 53	4 86	107 3
3-row	24	4	1.46	310,400	264,100	4 89	5 36	109 6
1-row	24	sp. pl	17 pls.	25,179	26 540	6 18	7 43	120 2

The type of plats together with the rate of planting is also given in Table 6. From a comparison of the 3-row blocks spaced 18 and 24 inches between the rows, it is obvious that the variation in the original rate of seeding made in 1933 did not have a great influence on the number of plants found in the spring of 1938. Natural competition doubtless accounts for this equalization in number of plants since both varieties are winter hardy. This lends weight to the conclusion that there may be a fairly wide range in rate of seeding, provided a sufficiently good stand is obtained.

An interesting feature of the results presented in Table 6 has to do with the relative crown spread of the two varieties. As an average in the solid-drilled rows Ladak had from 2.4% less to 9.7% greater spread of crown than Hardistan, but in the space-planted material (one plant per foot) Ladak had a 20.2% greater spread. This greater crown spread may account for the increased yield of Ladak over Hardistan under space-planted conditions, amounting to 11 and 9% (Table 1) above the solid-drilled field plats in 1936 and 1937, respectively. This also leads to the important conclusion that differential response of varieties in occupying the land may lead to a fundamental error in space-planted yield tests of alfalfa.

EFFECT OF AREA OF FIELD INCLUDED IN TEST UPON VARIABILITY OF NURSERY YIELDS

Variability studies of yields of similar plats combining various areas in the nursery resulted in finding significantly less variability

within small areas as compared with larger areas. This again emphasizes the desirability of keeping the land area as small as possible after considering other necessary factors.

NUMBER OF REPLICATIONS OF THE DIFFERENT PLAT TYPES REQUIRED TO MAKE A 5% DIFFERENCE IN YIELD STATISTICALLY SIGNIFICANT

Table 7 has been prepared to give the standard deviations of all types of plats based on the mean yields for the three years 1935, 1936, and 1937. The mean yields are also given and the standard errors in per cent of the mean Two further columns are added, the first giving the number of replications required to make a 5% difference in yield statistically significant and the second based on calculations similar to those made by Immer[4] showing the relative efficiency of the land with different types of plats

The number of replications required to make a 5% difference in yield statistically significant is obtained by multiplying the standard error in per cent of the mean by $\sqrt{2}$ to obtain the standard error of a difference, multiplying this by 2 for the conventional minimum level of significance, then dividing this total by 5, which is the assumed percentage difference in yield This figure is the value of the $\sqrt{n}$, which, when squared, gives the number of replications required The equation for the field plats becomes $\frac{3.3\sqrt{2} \times 2}{\sqrt{n}} = 5$(per cent difference in yield), where n is the number of replications required

The results of these calculations indicate that there is a wide difference in the number of replications required for a given level of significance, depending on the type of plat. As would be expected, the field plats show to advantage, requiring only 3.5 (4) replications, on the average, while the single space-planted rows 24 inches apart require 15.7 (16) replications to obtain the same accuracy. Other types of plats are intermediate, although they vary considerably, depending on the error involved. This variability emphasizes the fact that rigid conclusions regarding the number of replications cannot be drawn from one set of data; the results, however, indicate certain trends which should be considered in a decision as to the type of nursery plat to be used.

For the calculations of plat efficiency in the last column of Table 7, the area of land for each plat is taken into consideration as well as the number of replications required to obtain a statistically significant difference with a 5% difference in yield. It is obvious that in this calculation the smaller-sized plats have a distinct advantage provided the error is not too large. If, as in this case, the single-row plat, with rows spaced 18 inches apart, is arbitrarily considered 100%, all other types of plats are lower in land-use efficiency. These results, however, must be used with caution because other factors, such as

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[4]IMMER, F. R. Size and shape of plat in relation to field experiments with sugar beets. Jour. Agr. Res., 44: 649-668. 1932

TABLE 7.—*Standard error and mean yield of different types of plats, the theoretical number of replications required to reduce the error to such a value that a 5% difference in mean yield of two varieties would be statistically significant, and the relative efficiency of the types of plats used, average of 1935, 1936, and 1937 crops.*

Kind of plat	Standard deviation, lbs.	Mean yield of two varieties, lbs.	Standard eror in per cent of mean	No. reps. required to make a 5% difference in yield statistically significant	Relative efficiency of plat, %
Field plats	107	3,233	3.3	3.5	12.2
Four middle rows of 8-row plat	167	3,861	4.3	5.9	47.0
All 8 rows of 8-row plat	163	4,075	4.0	5.1	54.3
Two middle rows of 4-row plat	247	4,010	6.2	12.3	45.4
All 4 rows of 4-row plat	192	4,268	4.5	6.5	85.9
Middle row of 3-row plat, 18-in. spacing	260	3,877	6.7	14.4	20.1
All 3 rows of 3-row plat, 18-in. spacing	167	3,848	4.3	5.9	48.7
Single-row plat, 18-in. spacing	198	3,820	5.2	8.6	100.0
Middle row of 3-row plat, 24-in. spacing	141	3,635	3.9	4.8	44.4
All 3 rows of 3-row plat, 24-in. spacing	136	3,638	3.7	4.4	49.4
Single-row plat, 24-in. spacing	163	3,586	4.6	6.8	95.9
Single-row plat, 24-in. spacing, space planted	199	2,852	7.0	15.7	41.4

ease of handling, competition, etc., require consideration. Further studies bearing on these problems under various conditions would be helpful.

SUMMARY

By appropriate plantings, alfalfa nursery plat technic was studied with respect to number of rows per plat, distance between rows, alley space between plats, removal of border rows at harvest, interplat varietal competition, spacing of plants within the row, rates of planting, and plat distribution.

Two varieties, Hardistan and Ladak, were compared in 16 replications of nine types of nursery plats and adjacent field plats. The nursery plats were 16 feet long with variations of 1, 3, 4, and 8 rows per plat, while the row-spacings under comparison were 7, 18, and 24 inches All of these plats were solid-drilled except one group in which the plants were spaced 12 inches in rows 24 inches apart.

Yields were obtained during a 3-year period, 1935, 1936, and 1937, which analyzed comparatively and statistically indicated the following:

Solid-drilled plats with a 7-inch row spacing were definitely subject to serious interplat varietal competition The effects of this could be overcome by discarding border rows at harvest. Widening the alley space between plats to 12 inches also prevented a significant interaction between varieties. The relative yields from single- or multiple-row plats with either 18- or 24-inch row-spacing likewise exhibited no significant differential interaction and compared favorably with the yields from field plats. There were, however, some indications of interplat competition between single rows spaced 18 inches apart and one might expect this to be a possible source of error Space-planted nurseries would seem to be less accurate for yield determinations than solid-drilled rows for testing alfalfa strains, especially if they differ in rate of crown development

Rate-of-seeding tests in connection with multiple-row nursery plats in which the rows were spaced 18 and 24 inches apart indicate that there may be considerable latitude in the amount of seed sown, within reasonable limits, without significantly affecting the comparative varietal performance. When the seed was sown in equal amounts (15 pounds) per acre in rows spaced 7, 18, and 24 inches apart, the 18- and 24-inch rows yielded from 5 to 11% less than when the rate of seeding per row was the same as in the 7-inch rows. As the distance between nursery rows is increased much beyond 7 inches, it seems preferable to hold constant the amount of seed sown per row rather than the amount sown per acre. Plant mortality was far greater in the heavily-seeded rows and stands tended to equalize after 4 years.

Yields from nursery plats were analyzed statistically to study the effect of area of land on variability. Using the same yields and total area in the two comparisons, the yield variability for the entire nursery was significantly greater than when the replicates were restricted to any fourth of its area.

Comparison of adjacent unlike plat types showed striking and significant modifications in plat yields. For example, when a solid-

planted row was 7 inches from a space-planted row it gave an excess yield of 74%, while the space-planted row was depressed 63% in yield. Similar results were obtained when unequal adjacent spacings were involved. It seems evident that great care must be exercised in taking yields from adjacent rows which are apt to be either at an advantage or disadvantage with respect to spacing of rows or density of stand.

The number of replications required to make a 5% difference statistically significant has been calculated and found to vary from 4 to 16 for the different types of plats under these conditions.

Based on the specific principles indicated by these studies and also on general experience with alfalfa nurseries, the most serviceable types of plat for advanced nursery testing appear to be somewhat optional among the following: (1) Solid-drilled 5 to 8 rows spaced 7 inches apart, with a 12- to 14-inch alley between border rows; or (2) solid-drilled 3 to 5 rows spaced 12 inches apart with an 18-inch alley between border rows. Since removing border rows is difficult and expensive with this crop and since very little error has been found with such plats due to border effect, it is suggested that the entire plat may be harvested for yield, with the possible exception of removing border rows in case adjacent stands are decidedly different. This would also facilitate machine harvesting. The plats may be 16 feet or more in length, depending on circumstances, and the alley space should be included in the plat area Single rows spaced 18 to 24 inches apart are permissible for preliminary nursery testing.

PHOSPHORUS FIXATION BY HORIZONS OF VARIOUS SOIL TYPES IN RELATION TO DILUTE ACID EXTRACTABLE IRON AND ALUMINUM[1]

Dale S. Romine and W. H. Metzger[2]

In a study of relative phosphorus fixation by several horizons of each of a number of soil types, interest centered in a possible relationship between the dilute acid extractable iron and aluminum and the phosphorus-fixing capacity of the various horizons. The relationship was studied by determining phosphorus absorption by the soil in its original condition and again determining absorption after the available phosphorus had been extracted by the method of Truog (8).[3] Truog's method of extraction was used because it involves the use of a very dilute acid and it removes the "available" phosphorus from the soil fairly accurately. The acid can remove only small amounts of iron and aluminum because of the degree of dilution, but it was believed that this dilute acid extractable iron and aluminum might be closely related to the ability of the soil to take up phosphorus from solution.

It is generally recognized that phosphorus availability not only varies with the different forms in which phosphorus is fixed in the soil, but apparently there are varying degrees of availability within the same form.

Truog (9) has shown that at least a portion of the phosphorus in precipitated ferric and aluminum phosphates is available to plants. Heck (4) states that when active calcium and aluminum are low, phosphates are fixed largely by iron and the resulting compound is generally less soluble than the corresponding aluminum compound.

Ford (2) reports that hematite did not appear to fix phosphates, whereas goethite fixed large amounts. McGeorge and Breazeale (6) observed that iron and aluminum hydrogels fixed large amounts of phosphorus which was insoluble in water but completely soluble in dilute HCl. Meyer (7) believes an iron compound to be responsible for the fixation of phosphorus in soils of the South. It occurs in concretions and fixes phosphorus as a basic ferrous phosphate. Heck (5) found that dark-colored soils containing abundant organic matter were generally low-fixing soils. Reddish yellow or yellow soils have the highest fixing power. This color arises from the presence of monohydrate (and perhaps dihydrate) ferric oxide, which is highly reactive. Truog and Ford (10) state that yellow-colored soils fix phosphorus more readily than do red-colored soils because of a difference in the form of iron compounds in these soils. Hance (3) states that subsoils show higher fixing power than surface soils. He defines a high-fixing soil as one that allows the soluble phosphates to penetrate 2 or 3 inches and a mild-fixing soil as one that allows penetration to a depth of 2 or 3 feet.

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[1]Contribution number 284 from the Department of Agronomy, Kansas State College, Manhattan, Kans. Part of a thesis submitted to the Graduate School of Kansas State College by the senior author in partial fulfillment of the requirements for the degree of master of science.

[2]Graduate student and Associate Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 107.

SOIL PROFILES STUDIED

Since leached soils are comparatively high fixers of phosphorus, it was deemed advisable to confine this study primarily to relatively heavily leached soils. Representative profiles studied are briefly described below.

The Cherokee silt loam is a heavily leached prairie soil developed in the more nearly level areas of eastern Kansas. The lack of relief, together with the heavy claypan subsoil, renders drainage poor. The Labette silt loam is residual from gypsiferous shales and limestone. The lower part of the surface soil contains numerous iron concretions. The lower part of the subsoil is high in iron.

The Knox silt loam is an open, friable soil which has developed from loessial material. The profile studied was taken from very hilly topography. The Marshall silt loam is a dark-colored upland soil with a friable subsoil. The profile has developed from loessial deposits. The Derby silt loam is a friable, moderately leached soil of wind-blown origin.

The Summit silt loam has developed from the weathering of limestone and shale. Dark brown to black iron concretions and stains are numerous in the lower subsoil. The general topography of the region in which this soil occurs is undulating to gently rolling or rolling. The Shelby silt loam is derived from glacial till. The subsoil contains numerous iron concretions. The Idana silt loam is derived from calcareous shales and limestones. A few of the more nearly level areas are underlain by a somewhat heavy subsoil, approaching a claypan.

The Hays silt loam has developed on residual material from limestone. A lime zone is encountered in the subsoil, usually below 30 inches depth, but much shallower on slopes.

All of the above soils, except the Hays, lie in the prairie soils area in Kansas, and have developed under an average annual precipitation ranging from 30 to 40 inches. The Hays profile has developed under approximately 22 inches of average annual rainfall, and lies in the Chernozem belt.

ANALYTICAL METHODS

To determine the absorption of phosphorus by the original soil, 10-gram samples of 100-mesh soil from each horizontal subdivision were placed in a 200-ml. shaker bottle with 50 ml. of dilute phosphoric acid solution containing a known quantity of phosphorus. They were then placed on a shaker, agitated for 30 minutes, and filtered. The phosphorus concentration of the filtrate was determined by the Truog (8) method. It was assumed that the decrease in phosphorus content of the solution represented phosphorus fixed by the soil. No attempt was made to distinguish between fixation in easily soluble and in difficultly soluble form. In order to prevent an extreme variation in the phosphorus concentration of the filtrate, standardized phosphoric acid solutions of four different concentrations were used, *viz.*, 19 p.p.m., 38 p.p.m., 57 p.p.m., and 95 p.p.m. of elemental phosphorus, the strength used for each sample being determined by the amount of phosphorus the soil would absorb. The pH value ranged from 2.7 for the solution containing 95 p.p.m. to 3.1 for that containing 19 p.p.m.

Truog's buffered extracting solution has a pH value of 3.0. The soil-solution ratio used was 1:200 and the time of shaking was 30 minutes. Since the pH values of the phosphorus solutions used in the absorption studies were so nearly the same as that of the Truog solution, it was assumed that absorption as determined for the original soil should be comparable to that for extracted soil except for

changes induced by the extraction of the soil with the Truog solution. The pH values at which absorption took place were not measured but under these conditions must have been similar for the original soil and the extracted soil. The soil-solution ratios and the time of contact between soil and solution, as well as the manner of shaking, were kept constant throughout.

To determine the absorption after extraction of "available" phosphorus, the soil and extract from the Truog procedure were separated by centrifuging. This means of separation made possible the obtaining of the soil needed for the absorption determination with negligible mechanical loss. To the extracted soil thus obtained was added standard phosphoric acid solution of the same concentration as was added to the corresponding sample in the original absorption determination. The remaining procedure was identical with that used for the original determination.

The supernatant liquid obtained after centrifuging was divided into two aliquots. One was used to determine the "available" phosphorus according to Truog's procedure. To the other was added dilute NH_4OH to precipitate iron and aluminum and other substances precipitated by this reagent. The precipitate was separated by filtration, ignited, and determined as R_2O_3. All of the NH_4OH precipitates are expressed as R_2O_3 in Table 1. This appeared justifiable since the amount of phosphorus precipitated was negligible in comparison with the amount of sesquioxides.

The pH value of the soils was determined with the quinhydrone electrode, using a 1:1 soil-water ratio.

EXPERIMENTAL RESULTS

On account of the desirability of making comparisons of the data for one profile with those for another and also the importance of comparing the data for the various horizons within each profile, it appeared logical to group all of the data in a body. All data obtained therefore are presented in Table 1.

PHOSPHORUS ABSORPTION BY THE ORIGINAL SOIL

In all soils studied, the B horizon showed greater absorption than the A horizon. This was more pronounced in the more severely leached soils than in those less affected by leaching. The explanation for this probably lies in the fact that the B horizon is the zone of accumulation of iron and aluminum leached from the A horizon. It is recognized that the pH values at which absorption took place with samples from the various horizons were probably somewhat variable. However, the pH values of the B horizons were in most cases quite similar to those for the lower portion of the A horizons. Also, since the soil-solution ratio during absorption was 1:5 and therefore differences in the buffering effect of the soil samples on an acid with the buffering properties of H_3PO_4 were probably small, it appears that the influence of accumulated iron and aluminum in the B horizons is the most likely explanation for their high absorption values as compared to the A horizons.

A striking example of the indirect influence of leaching on phosphorus absorption was revealed in comparing the original absorption of the Knox profile with that of the Hays profile. It was found that

TABLE 1.—*Phosphorus absorption of various soils as related to dilute acid extractable R_2O_3, pH value, and soil type.*

Horizon and depth, in.	Phosphorus absorbed by original soil, p.p.m.*	Available phosphorus, p.p.m.	Apparent absorptive capacity, p.p.m.†	Phosphorus absorbed after extraction, p.p.m.	Reduction of absorptive capacity, p.p.m.	Reduction in absorptive capacity, %	R_2O_3 removed by extraction reagent (mgm per 100 grams of soil), mgm.	pH value
Cherokee Silt Loam (Labette County)								
A 0–4	47.5	14.6	62.1	20.0	42.1	67.8	50	5.91
A 4–12	65.0	4.5	69.5	27.0	42.5	61.2	40	5.26
A 12–18	80.6	4.0	84.6	32.5	52.1	61.6	50	4.97
A 18–20	88.4	4.0	92.4	55.0	37.4	40.5	57	4.98
B 20–23	179.4	4.0	183.4	97.5	85.9	46.9	120	5.12
B 23–28	176.5	4.0	180.5	95.5	85.0	47.0	130	5.51
C 34+	87.1	18.5	91.1	57.0	34.1	37.5	87	6.42
Labette Silt Loam (Allen County)								
A 0–2	71.2	19.0	90.2	40.0	50.2	55.6	35	5.58
A 2–14	83.7	7.5	91.2	45.0	46.2	50.5	45	4.86
B 14–24	180.5	5.0	185.5	135.0	50.5	27.0	87	4.84
C 24+	454.6	4.0	458.6	375.0	83.6	18.1	112	4.90
Knox Silt Loam (Doniphan County)								
A 0–8	72.2	38.0	110.5	25.0	85.5	77.4	45	7.32
B 8–24	75.0	60.0	135.0	23.5	111.5	82.6	62	6.65
C 24+	78.7	100.0	178.7	21.7	157.0	87.8	87	7.19
Marshall Silt Loam (Doniphan-Brown County Line)								
A 0–4	56.2	80.0	136.2	18.0	118.2	86.8	85	6.28
A 4–14	69.6	32.0	101.6	27.5	74.1	73.0	57	6.72
B 14–30	88.6	14.0	102.6	50.0	52.6	51.0	75	6.04
C 30+	84.2	45.0	129.2	45.0	84.2	65.2	120	6.04

				Derby Silt Loam (Clay County)				
A 0–3	46.2	24.0	70.2	25.0	45.2	64.4	22	6.59
A 3–9	69.9	25.0	94.0	40.0	54.0	57.5	40	5.60
A 9–17	146.2	12.5	158.7	75.0	83.5	52.5	50	5.55
B 17–27	160.0	13.6	173.6	75.0	98.6	56.8	60	5.65
C 27+	80.9	51.2	132.2	40.0	92.2	69.5	45	6.84
				Summit Silt Loam (Allen County)				
A 0–2	58.2	24.0	82.2	35.0	47.2	57.5	30	5.64
A 2–13	85.0	4.0	89.0	45.0	44.0	49.4	45	5.59
B 13–28	432.0	4.5	438.5	332.5	106.0	24.2	102	5.58
C 28+	411.0	10.0	421.0	320.0	101.0	24.0	95	6.82
				Shelby Silt Loam (Leavenworth County)				
A 0–4	76.5	17.0	93.5	15.0	78.5	84.0	60	5.52
A 4–7	80.9	12.5	93.4	15.0	78.4	84.0	67	5.42
B 7–20	358.8	6.5	364.5	225.0	139.5	38.2	127	5.52
C 20+	347.9	42.0	389.9	255.0	134.9	34.6	117	6.18
				Idana Silt Loam (Clay County)				
A 0–5	60.0	26.6	86.6	15.0	71.6	82.6	30	6.13
A 5–15	63.7	13.5	77.2	15.0	62.2	80.5	42	5.91
A 15–19	70.8	14.5	85.3	22.5	62.8	73.6	50	5.59
B 19–29	87.8	32.0	119.8	61.7	58.1	48.5	62	6.75
C 29+	80.8	33.3	104.1	55.0	59.0	56.7	50	7.84
				Hays Silt Loam (Smith County)				
1 0–12	78.1	52.0	130.1	10.0	120.1	92.3	60	6.45
2 12–30	81.5	60.0	141.5	15.0	126.5	89.4	67	6.84
3 30–38	75.0	62.5	137.5	10.0	127.5	92.7	87	7.49

*Parts per million parts of air-dry soil.
†Apparent absorptive capacity = available phosphorus plus phosphorus absorbed by original soil and is therefore an arbitrary value applicable only to the methods employed in this work.

original absorption values throughout the two profiles were nearly equal. The Knox profile has developed in a region having an average annual rainfall of about 35 inches, while the Hays profile has developed under approximately 22 inches of annual precipitation. Equal absorption by the two profiles, therefore, appears inconsistent with other findings in this study, namely, that the profiles which had developed under the heaviest rainfall exhibited the highest absorption. When it is considered that the Knox profile studied was developed on a very hilly topography, equality in absorption by the two profiles can be explained. Because of a hilly topography and consequently a greater run-off and more erosion, leaching has not been as extensive and therefore less effective in developing a zone of iron and aluminum accumulation than would be true with equal rainfall on more level areas in the same environment. The hilly topography has apparently offset the difference of 13 inches in rainfall so that the Knox and the Hays profiles are comparable in that neither has developed a marked zone of iron and aluminum accumulation. This is further evidenced by their comparable pH values.

"AVAILABLE" PHOSPHORUS IN THE ORIGINAL SOILS

In all horizons low availability was associated with low pH values as revealed in Fig. 1. This is probably due to the lack of strong bases

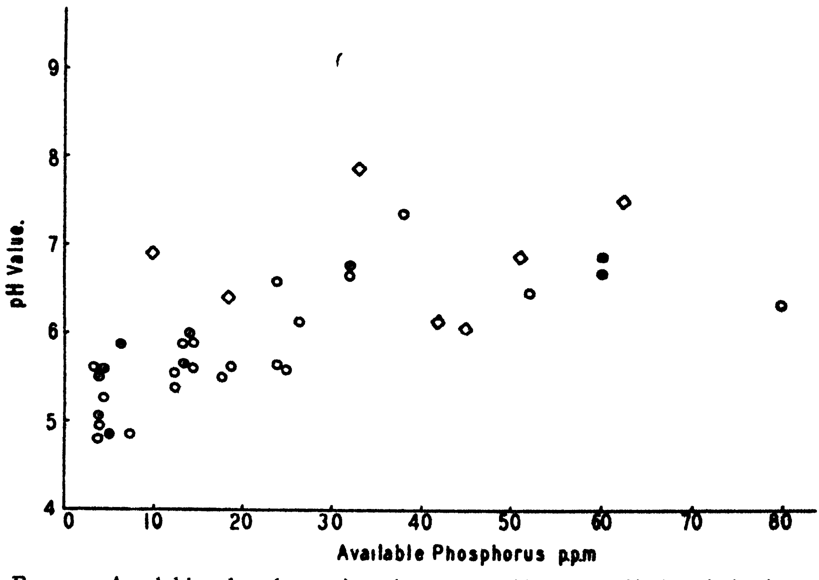

FIG. 1.—Available phosphorus in relation to pH value. Circle = A horizon; Circle with dot = B horizon; Diamond = C horizon.

indicated by low pH values and a consequent increase in the activity of iron and aluminum in phosphorus fixation.

In the more severely leached soils low availability extended throughout the lower part of the profile, while in the relatively un-

leached soils "available" phosphorus tended to increase with depth, reaching a maximum in the C horizon.

No well-defined relationship appeared to exist between the R_2O_3 extracted by the Truog extracting solution and the available phosphorus of the various horizons. However, in the relatively unleached profiles (Hays, Knox), it was found that comparatively high "available" phosphorus was associated with a relatively high amount of dilute acid extractable R_2O_3 in all horizons.

Generally speaking, lowest availability occurred in the B horizons. This is in agreement with the well known and widely recognized low availability of phosphorus in subsoils as indicated by plant growth. Since B horizons show high absorptive capacity and low availability of phosphorus, there is suggested the idea of using the absorptive capacity of the soil rather than the amount of "available" phosphorus extracted as a measure of the soil's need for phosphorus

PHOSPHORUS ABSORBED AFTER EXTRACTION OF SOIL WITH TRUOG'S REAGENT

In all cases the extraction of "available" phosphorus reduced the capacity of the soil to absorb phosphorus as shown in Table 1. The percentage reduction was highest in the soils which had been subjected to least leaching. In all of the soils studied the percentage reduction in the A horizon was greater than either the B or C horizons.

The B and C horizons of the Shelby, Summit, and Labette profiles exhibited comparatively high absorption after extraction, as shown in Table 1. It is of interest, however, to note that the reduction in absorptive capacity in these horizons compared rather favorably with other findings in this study, namely, that there is a general relationship between the R_2O_3 extracted and the reduction in "apparent absorptive capacity" available phosphorus plus original absorption. The relation between R_2O_3 extracted and the reduction in "apparent absorptive capacity" is indicated in Fig. 2. These data suggest the possibility that plants grown on leached soils are dependent for available phosphorus largely upon phosphorus combined with the sesquioxide constituents.

SESQUIOXIDES EXTRACTED BY TRUOG'S REAGENT

Under the conditions established, it was believed that by adding the available phosphorus to that absorbed by the original soil, a measure of its absorptive capacity would be obtained. The values so obtained were designated "apparent absorptive capacity." These values were plotted against the R_2O_3 extracted and a scatter diagram is shown in Fig. 3. The five isolated points at the right hand side of the figure represent values for both the B and C horizons of the Summit and Shelby profiles and the C horizon of the Labette profile. It is apparent that the relatively high absorption in these horizons is due in part to factors other than extractable sesquioxides. One of the authors has shown that the B and C horizons of these profiles contain from 50 to 65% of particles of colloidal size. This very high content of colloids may offer an explanation of the behavior of these

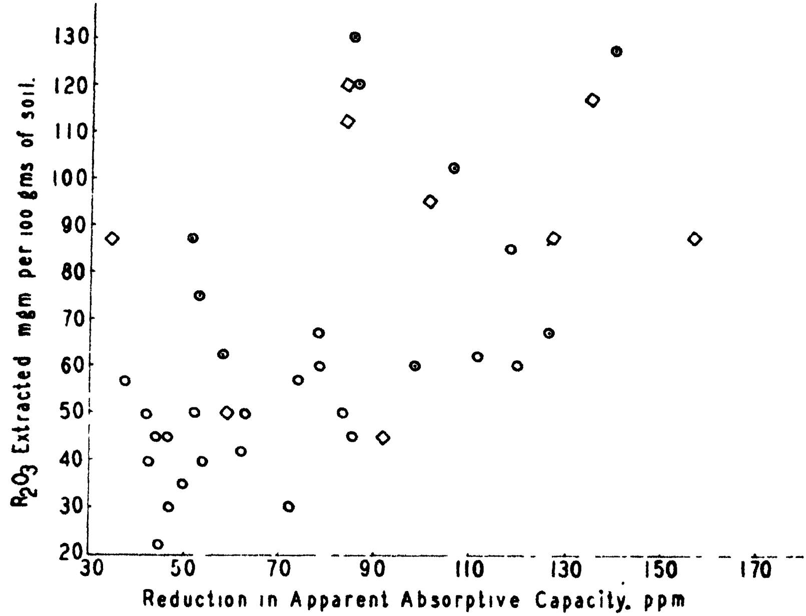

FIG. 2.—Relationship between R_2O_3 extracted and reduction in apparent absorptive capacity. Circle = A Horizon; Circle with dot = B Horizon; Diamond = C Horizon.

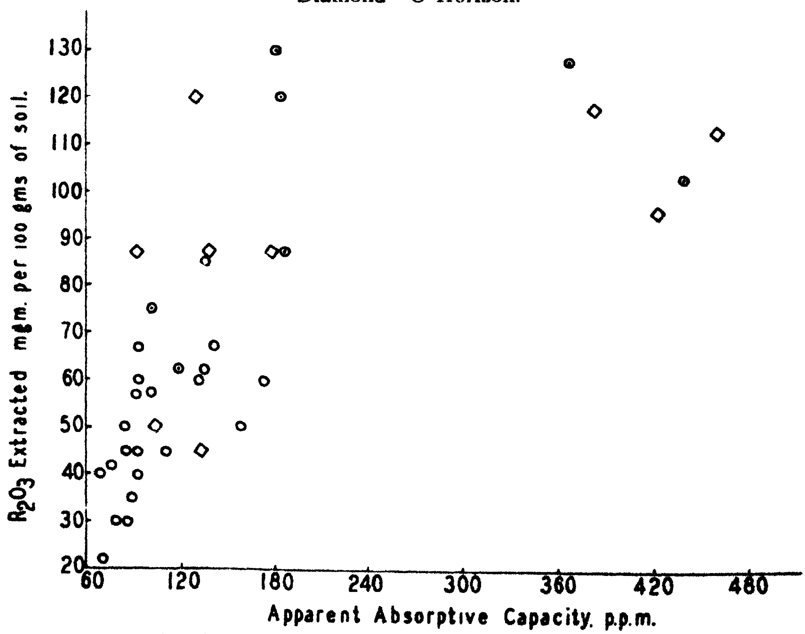

FIG. 3.—Relation between R_2O_3 extracted and apparent absorptive capacity. Circle = A Horizon; Circle with dot = B Horizon; Diamond = C horizon.

profiles due to surface absorption of phosphorus as proposed by Bradfield, Scarseth and Steele (1). It may also be true that the extracting solution, which was 0.002 N with respect to H_2SO_4 and contained 3 grams of $(NH_4)_2SO_4$ per liter, was too weak to remove more than a very small portion of the abundant free iron from these horizons. Hence, the absorption after extraction might be greater in proportion to the original absorption than in soils in which a larger portion of the free iron was removed by the extracting reagent.

Data presented in Table 1 reveal that B horizons of the relatively leached soils are generally deficient in "available" phosphorus and that low availability is usually associated with a high absorptive capacity. Therefore, from a practical point of view, not only is the amount of "available" phosphorus important, but also the degree to which the constituents capable of absorbing phosphorus are saturated by this element.

SUMMARY

Relative phosphorus-fixing capacity of several horizons of each of a number of soil types has been studied and an attempt made to determine the possible relationship between the dilute acid extractable R_2O_3 and the phosphorus-fixing capacity of the various horizons.

Extraction of "available" phosphorus by Truog's solution reduced the capacity of the soil to absorb phosphorus The percentage reduction in absorption after extraction of "available" phosphorus was highest in the relatively unleached soils. The percentage reduction in the A horizons was greater than in either the B or C horizons

In all horizons the reduction in "apparent absorptive capacity" (available phosphorus plus phosphorus absorbed by original soil) resulting from extraction of the soil by the Truog reagent varied with the general trend of the R_2O_3 extracted

The B and C horizons of rather heavily leached soils absorbed from 2 to 5 times as much phosphorus as did the B and C horizons of the relatively unleached soils. In all cases the B horizons showed greater absorption than the A horizons

Generally speaking, lowest availability occurred in the B horizons. In the unleached profiles, high "available" phosphorus was associated with relatively high amounts of extractable R_2O_3 Low availability was associated with low pH values.

LITERATURE CITED

1. BRADFIELD, RICHARD, SCARSETH, GEORGE, and STEELE, J G. Factors affecting the retention of phosphate by clays. Trans. Third Int. Cong. Soil Sci., 1:74 75. 1935
2. FORD, M. C. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25:134 144. 1933.
3. HANCE, F. E. Phosphate fixation in Hawaiian soils. Hawaii Planters' Rec., 37:182 196. 1933.
4. HECK, A. F. Phosphate fixation and penetration in soils. Soil Science, 37:343-355. 1934.
5. ——————. Availability and fixation of phosphorus in Hawaiian soils. Jour. Amer. Soc. Agron., 27:874-884. 1935.

6. McGeorge, W. T., and Breazeale, J. F. Studies on iron, aluminum and organic phosphates and phosphate fixation in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 40. 1932.
7. Meyer, A. H. Phosphate fixing compounds in the soil. Soil Science, 71:457. 1930.
8. Truog, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:873–882. 1930.
9. ———. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41. 1916.
10. ——— and Ford, M. C. New science for an old art. Wis. Agr. Exp. Sta. Bul. 410:6–8. 1930.

STORAGE OF SUGAR BEETS UNDER CONDITIONS OF HIGH HUMIDITY AND LOW TEMPERATURE[1]

JOHN O. GASKILL AND H. E. BREWBAKER[2]

STORAGE of sugar beets for breeding purposes has been accomplished in the past in a number of ways. The methods most commonly employed included the root storage cellar and the pit silo or trench, in each of which the beets as a rule were covered by or packed in some moisture-holding medium, such as moist sand, as recommended by Pack (3),[3] or ordinary moist field soil. Straw cover has been used to some extent, and Harris (1) reported satisfactory results from storage in dry sand. Kohls (2) reported that mother beets coated with paraffin and stored in crates in a root cellar, without sand or any other covering or packing material, kept satisfactorily. For best results it was necessary to remove the paraffin from the root sutures before planting. The importance of minimizing loss of water from the roots apparently has been rather generally recognized, and was emphasized by Pack.

For the period between harvest and analysis, Pack (4) suggested piling without packing material in a ventilated but covered pit in order to induce a more uniform moisture content. He recommended that the roots be analyzed within a relatively short period after harvest and then be stored over winter in moist sand.

This paper describes a method of moist cellar storage in which considerable economy of labor is effected through elimination of paraffin, sand, or other treatment. The loss of sucrose which occurred in beets stored by this method is compared with that which occurred with the ordinary pit silo.

METHODS

Several crates of mother beets were stored satisfactorily throughout the entire winter of 1933-34 in a root cellar at the U. S. Sugar Plant Field Station, Fort Collins, Colo, without the use of paraffin coating, packing material, or cover of any kind. These roots, after about 2 months of storage, were rasped as though for analysis and then returned to the cellar, simulating approximately the usual routine of handling mother beets at the station. Temperatures a few degrees above the freezing point and high humidity were maintained. No loss in weight occurred, other than that resulting directly from the removal of a portion of each root in the rasping operation, foliage growth was slight, and the beets were in good condition at the end of the storage period.

In the fall of 1934, this method of storage was adopted for general use at the station. Satisfactory results were obtained during the two winters which followed,

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[3]Figures in parenthesis refer to "Literature Cited", p. 115.

and in 1936 a reinforced concrete cellar (Figs. 1 and 2), 12 feet wide and 32 feet long, was constructed which was designed to permit control of temperature and humidity without the use of refrigerating apparatus. In general, the procedure employed for sugar beet storage with this cellar is as follows: Beets are washed, numbered with indelible pencil, and placed in crates which are so arranged as to facilitate circulation of air. For a short time during the early fall, cakes of ice are placed in the center aisle, and air is circulated within the room, passing from the fan directly over the ice. Later, when nights are cooler, the use of ice is discontinued, outside air is drawn into the cellar at night, the ventilators being kept closed during the day. While in operation for cooling purposes, the fan is thermostatically controlled, being shut off as temperature in the cellar approaches the freezing point. Throughout the remainder of the storage period, it is used continuously for circulation of air within the room. High humidity is maintained throughout most of the storage season by means of two overhead nozzles which operate under city water pressure and produce a misty spray. During the early fall, supplemental moisture is provided by daily sprinkling of crates and cellar

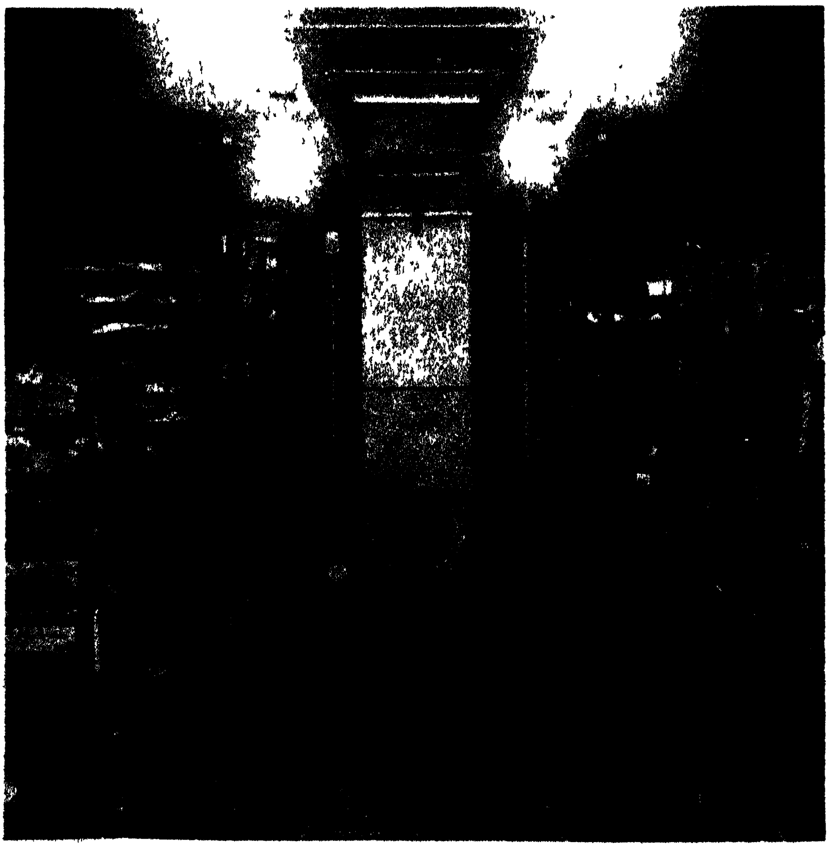

FIG. 1.—Interior view of root storage cellar, Fort Collins, Colo., showing overhead conduit and thermostatically controlled, 12-inch ventilating fan which serve both for intake of air and for circulation.

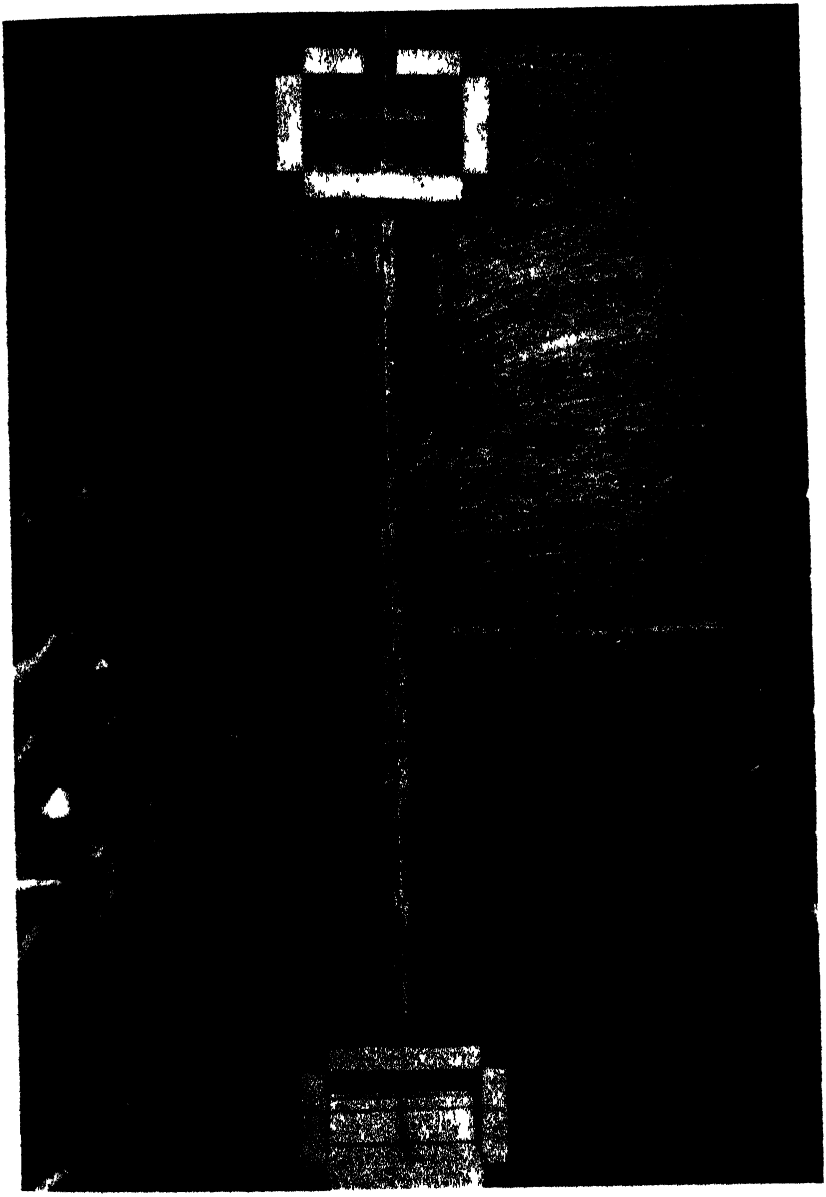

FIG 2 —Interior view of one of the four pairs of exhaust vents in root storage cellar The shutters are controlled manually from the center aisle (note over head levers near the rear in Fig. 1) and may be used to liberate air from either the top or bottom of the room

walls, plus thorough drenching of the beets one or twice each week. Drainage is provided by means of a pit located under the slatted aisle floor.

The feasibility of storing mother beets by such methods having been demonstrated, a test was conducted during the winter of 1936-37 to compare this type of storage with pitting in the field.

EXPERIMENTAL

In the latter part of October 1936, approximately 650 sugar beet roots of a commercial variety were washed and trimmed in the usual manner for mother beets and placed in crates in the cellar. On November 23, these roots were divided by a random method into five identical lots, numbered from 1 to 5. Each root in lot 1 was weighed and analyzed for sucrose percentage immediately, using the boring method recommended by Sherwood (5) for individual beets. Lots 2, 3, and 4 were stored in crates in the cellar for periods of 41, 84, and 125 days, respectively, and lot 5 was stored in an ordinary outdoor silo for 125 days. The silo conformed to the usual type employed commercially in northern Colorado, consisting of a trench 1 foot deep and 6 feet wide, in which the beets were piled and covered with moist soil to a depth of approximately 3 feet. All roots in lots 2, 3, 4, and 5 were weighed and analyzed immediately after removal from storage. The procedure of analyzing each beet before and after storage, as followed by various investigators, was not used in this experiment since study of the rate of loss of sucrose in normal, uninjured beets was the principal object of the test.

Temperature and relative humidity were recorded continuously in the cellar during the period of the experiment by means of a hygrothermograph. Actual temperature in the silo was not recorded, but records provided by the Colorado Agricultural Experiment Station served to indicate approximate outdoor temperature conditions existing throughout the duration of the experiment. Mean weekly temperature and relative humidity data are shown in Fig. 3. The average cellar temperature during the 125-day period was 35.9° F and relative humidity averaged 96.5%. The mean outdoor air temperature was 26.8° F.

The summarized data for weight and sucrose are presented in Table 1 and Fig. 4. None of the differences between lots, in average weight per root, was significant, as indicated by the negative "z" value and the relatively large difference required for significance. The gradual but significant decline in sucrose percentage which occurred in roots stored under cellar conditions was accompanied by an approximately equivalent loss in the silo, as indicated by the means for lots 4 and 5. Because of the direct effect of weight changes, however slight, upon sucrose percentage, the actual weight of sucrose per root, or sucrose content, is a more accurate measure of gain or loss in this respect. These data show a loss in sucrose, in both silo and cellar, which followed the same general trend as with the percentage figures, but experimental error was relatively greater, and the total loss of sucrose in 125 days of storage was not significant, indicating that 130 beets per lot were not sufficient to measure adequately the small decline in sucrose content which occurred under the conditions of this experiment.

TABLE 1 —*Loss of sucrose from sugar beets under moist cellar and under pit silo conditions, Fort Collins, Colo., Nov. 24, 1936, to March 29, 1937*

Lot No.	Method of storage	Date of analysis	Length of storage, days	Av. wt. per root, lbs.	Av. sucrose, %	Av. sucrose per root, lbs.	% loss in weight of sucrose per root: Total	% loss in weight of sucrose per root: Per day
1		Nov. 24, '36	0	1.452	15.74	0.2280		
2	Cellar	Jan. 4, '37	41	1.416	15.53	0.2194	3.77	0.09
3	Cellar	Feb. 16, '37	84	1.491	15.09	0.2247	1.45	0.02
4	Cellar	Mar. 29, '37	125	1.460	14.77	0.2158	5.35	0.04
5	Pit silo	Mar. 29, '37	125	1.477	14.68	0.2171	4.78	0.04
z				0.1114	1.3359	0.0280		
5% point				>0.8630	<0.4632	>0.4319		
1% point				>1.3000	<0.6472	>0.5999		
S.E. of mean				0.0319	0.121	0.00505		
Diff. for significance (odds approx. 19:1)				0.090	0.34	0.0143		

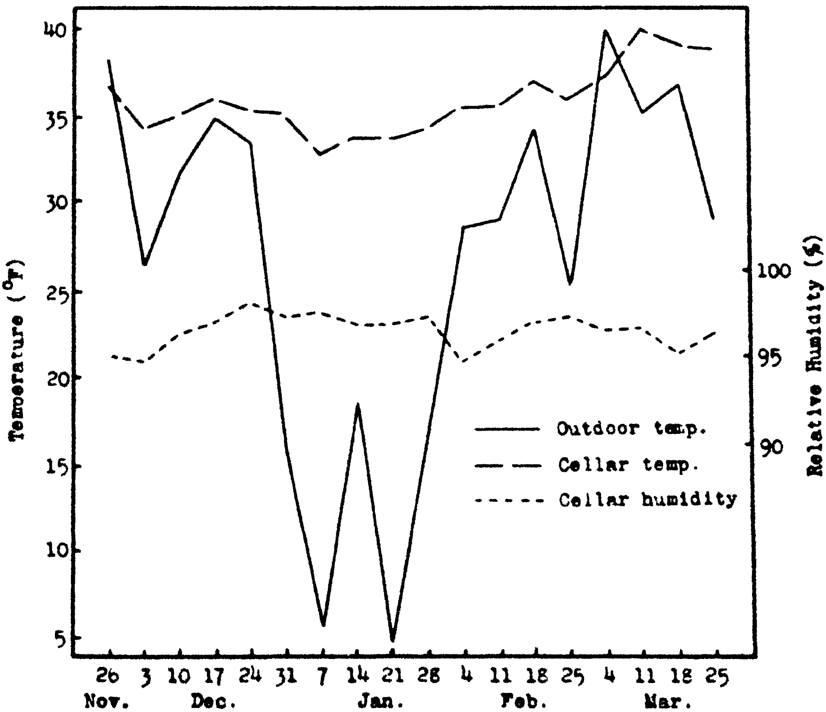

FIG. 3.—Mean weekly outdoor temperature and temperature and relative humidity in cellar, Fort Collins, Colo., 1936–37.

Recognizing this fact, definite conclusions cannot be reached regarding comparative rates of sucrose loss in cellar and silo. The data suggest, however, that the two methods of storage were approximately

equal when compared on the basis of preservation of sucrose. As shown in Table 1, the loss of sucrose in both cellar and silo averaged 0.04% per day, which, because of negligible change in weight and absence of rot, may be attributed largely to respiration, on the assumption that the proportion of the sucrose loss which could be accounted for by an increase in reducing sugars was relatively slight,

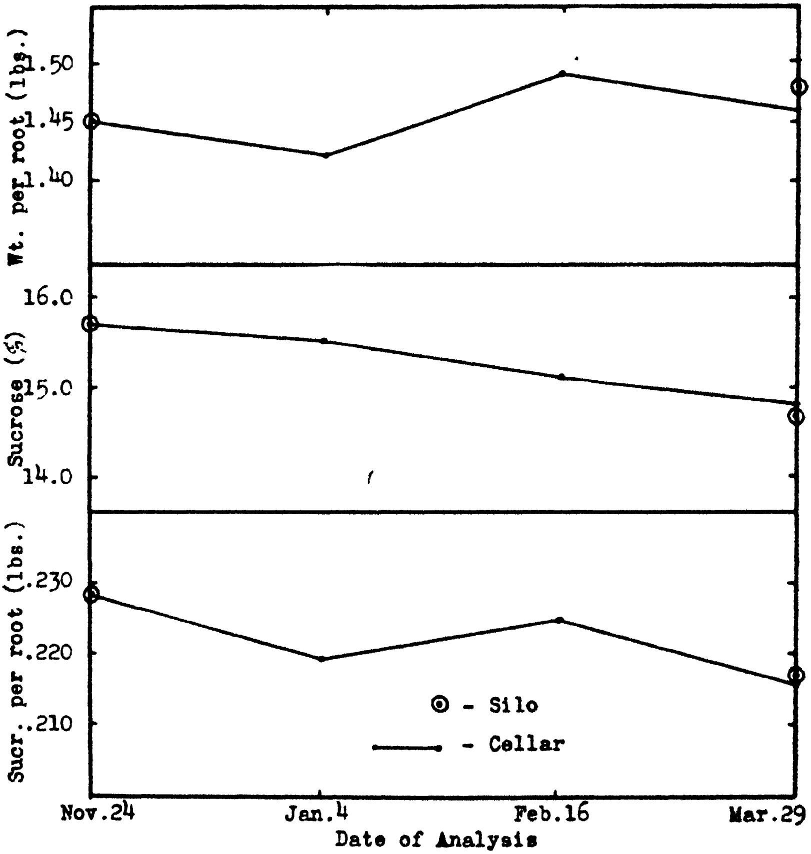

FIG 4.—Loss of sucrose from sugar beets under moist cellar and under pit silo conditions, Fort Collins, Colo., 1936-37.

as was indicated by data presented by Pack (3). It is of interest in this connection that Pack reported a loss of sucrose which amounted to 0.12% per day in beets which were stored in moist sand for 98 days at a temperature of 1.7° C—approximately equal to the average temperature recorded in the Fort Collins cellar during the 125-day storage period. The larger rate of loss reported by Pack may be accounted for, at least in part, by the fact that the roots in his experiment were analyzed before as well as after storage, while those in the Fort Collins test remained uninjured until the end of storage.

Rotting of roots was not a factor in this storage test irrespective of whether cellar or pit-silo was used. However, serious losses of stored roots through fungus attack, freezing, or suffocation have not been infrequent with sugar beets kept in pits or packed in moist sand in the ordinary root cellar. Among the causes of loss of roots, fungus decay has been important. Starting with a few individuals, rotting shortly involves surrounding roots. The increase in temperature within a covered storage pile, which is brought about by the respiration of the decay-producing organisms, accelerates fungus activity so that the spread of rotting is rapid and serious loss may occur within a short time. In the five years' experience with storage in open crates with temperature and humidity controlled as described, only negligible losses from rotting have occurred.

SUMMARY

During five winter storage periods, sugar beet roots being saved for seed production have been kept with negligible loss from rotting in open crates, without any coating or packing material, by maintaining the temperature of the root cellar a few degrees above freezing, the humidity near saturation, and by providing for thorough air circulation.

It was found by test that sugar beets stored 0, 41, 84, and 125 days in the cellar, or 125 days in an outdoor pit-silo, did not differ significantly in root weight. Gradual but statistically significant decline in sucrose percentage occurred with the longer storage periods. Under the conditions, sucrose loss averaged 0.04% per day, attributed largely to respiration. Comparison of cellar-stored and pit-siloed roots after 125 days storage indicated equivalent behavior.

The cellar storage method as described is convenient and efficient for storing small lots of sugar beet breeding strains.

LITERATURE CITED

1. HARRIS, FRANK S. The commercial production of sugar beet seed in Utah. Utah Agr Col Exp. Sta Bul. 136. 1915.
2. KOHLS, H. L. Use of paraffin for overwinter storage of sugar beets. Jour. Amer. Soc. Agron., 26:846–851. 1934.
3. PACK, D. A. The storage of sugar beets. Facts About Sugar, 19:178–180; 208–209; 232–235; and 251–253. 1924.
4. ———. The storage of mother beets. Facts About Sugar, 20:874–875. 1925.
5. SHERWOOD, S. F. Sucrose in seed beets. Sugar, 23:299–300. 1921.

DETERMINATION OF THE WEIGHT OF WATER IN A SOIL OR SUBSOIL MASS IN WHICH THE MOISTURE CONTENT INCREASES WITH DISTANCE FROM A PLANT OR GROUP OF PLANTS[1]

M. L. JACKSON AND M. D. WELDON[2]

IN a soil mass in which the moisture content is uniform, the computation of weight of water is relatively simple. A more involved process is required for the computation, however, when the water content varies with distance from a plant. Such distribution is encountered in subsoil moisture studies in orchards (4, 5)[3] and possibly in lysimeter and other moisture studies. The purpose of this paper is to present formulas suitable for calculating the weight of water in soil and substrata in which the moisture content is not uniform but varies systematically.[4] The formulas are applicable to fields in which plants or hills are regularly spaced, and several possible spacings are considered.

Ordinary arithmetical operations suffice in applying the formulas, although higher mathematics[5] is required in their derivations. Attempt has been made to explain the logic of the derivations in such a way as to facilitate their modification and re-arrangement to fit the individual needs of the user. Suggestions are made where further development may be desirable.

INCREASE IN MOISTURE CONTENT WITH DISTANCE FROM PLANT

The simplest case is that in which, first, the angular rotation about the plant does not affect the moisture content, that is, points at equal distances from the plant have equal moisture contents, and second, the increase in moisture percentage is proportional to the distance from the plant. The general equation which expresses these relationships is the equation for a straight line:

$$y = mx + b \tag{1}$$

in which y is the amount of water (pounds per cubic foot of soil), x is the distance from the plant in feet, and m and b are constants to be evaluated from data obtained in the field. The field data in Table 1 will now be used to illustrate the calculation of m and b.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 127.

[4]The authors are indebted to C. C. Wiggans, Department of Horticulture, University of Nebraska, for some illustrative data used in this paper.

[5]Acknowledgments for checking the mathematics involved, are made to Dr. C. Eisenhart, Instructor in Mathematics, University of Wisconsin, and Station Statistician, Wisconsin Agr. Exp Sta., Madison, Wis., and to Miss Zoe F. Schnabel University Computer, Department of Mathematics, University of Wisconsin.

TABLE 1.—*Field moisture data illustrating increasing moisture content with distance from plant.*

Points on graph (Fig. 1)		A (x_1, y_1)	B (x_2, y_2)	C (x_3, y_3)
Distance from plant, feet		$q_1 = 1.50$	$q_1+q_2 = 15.0$	$q_1+q_2+q_3 = 22.3$
Available water content	%	$P_1 = 6.80$	$P_2 = 8.20$	$P_3 = 9.70$
	lbs./cu. ft.*	5.52	6.66	7.88

*Pounds soil/cu. ft. = gm soil/cc × cc/cu. ft. × lbs./gm
= gm/cc × $(2.540 \times 12)^3$ × 0.0022046 = gm/cc × 62.43

Gm soil/cc = Volume-wt. = $\frac{\text{wt. sample of soil}}{\text{volume it occupied}}$ = apparent density.

With a soil volume-wt. of 1.3, lbs. water/cu. ft. = $\frac{\%H_2O}{100} \times 1.3 \times 62.43$
$= \%H_2O \times 0.812$

The two-point form of an equation for a straight line, from geometry (1), is

$$\frac{x-x_1}{y-y_1} = \frac{x_2-x_1}{y_2-y_1} \tag{2}$$

When this is solved for y and rearranged,

$$y = \left[\frac{y_2-y_1}{x_2-x_1}\right]x + \left[y_1 - \frac{y_2-y_1}{x_2-x_1} \cdot x_1\right] \tag{3}$$

A comparison of equation (3) to (1) shows

$$m = \frac{y_2-y_1}{x_2-x_1}; \text{ and } b = y_1 - \frac{y_2-y_1}{x_2-x_1} \cdot x_1 \tag{4}$$

Taking values (x_1y_1) and (x_2y_2) from the table corresponding to straight line AB (Fig. 1) and assuming the volume-weight is 1.3,

$$m_1 = \frac{y_2-y_1}{x_2-x_1} = \frac{(8.2-6.8)\ 1.3 \times 62.43}{100\ (15.0-1.5)} = 0.0842 \tag{5}$$

$$b_1 = \frac{6.8}{100} \times 1.3 \times 62.43 - 0.0842 \times 1.5 = 5.52 - 0.13 = 5.39 \tag{6}$$

and,

$$y = 0.0842x + 5.39 \tag{7}$$

Or from values (x_1y_1) and (x_3y_3) from the table corresponding to the straight line AC in Fig. 1:

$$m_2 = \frac{y_3-y_1}{x_3-x_1} = \frac{(9.7-6.8)\ 1.3 \times 62.43}{100\ (22.3-1.5)} = 0.113 \tag{8}$$

$$b_2 = \frac{6.8}{100} \times 1.3 \times 62.43 - 0.113 \times 1.5 = 5.52 - 0.17 = 5.35 \tag{9}$$

and,

$$y = 0.113x + 5.35$$

These specific cases illustrate the general expression (1) $y = mx + b$ in which m and b are expressed in terms of soil moisture by means of expression (4) and the values in Table 1:

$$m = \frac{y_2-y_1}{x_2-x_1} = \frac{(P_2-P_1) \times \text{Vol. wt.} \times 62.43}{100 \times q_2} = \frac{\text{Vol. wt.} \times 62.43}{100}\ \frac{P_2-P_1}{q_2} \tag{10}$$

$$b = y_1 - \frac{y_2 - y_1}{x_2 - x_1} x_1 = \frac{P_1}{100} \times \text{Vol wt.} \times 62.43 - mq_1$$

$$= \frac{P_1}{100} \times \text{Vol. wt.} \times 62.43 - \frac{(P_2 - P_1)\ \text{Vol. wt.} \times 62.43 \times q_1}{100\ q_2}$$

$$= \frac{\text{Vol. wt.} \times 62.43}{100}\left[P_1 - \frac{(P_2 - P_1)\, q_1}{q_2}\right] = \frac{\text{Vol. wt.} \times 62.43}{100}\left[P_1 - (P_2 - P_1)\ \frac{q_1}{q_2}\right] \quad (11)$$

P_1 is the percentage of water at q_1 feet from the plant and P_2 is the percentage of water at q_1+q_2 feet from the plant (b is the moisture content under the plant, and is the content P_1 at q_1, less the difference $P_2—P_1$ multiplied by the ratio of distances q_1/q_2).

THE SUMMATION OR INTEGRATION OF MOISTURE CONTENT IN A SQUARE AREA SURROUNDING EACH PLANT

The most common spacing of plants is in the form of squares (Fig. 2). Each plant (or hill) may be considered to have the space KMQT

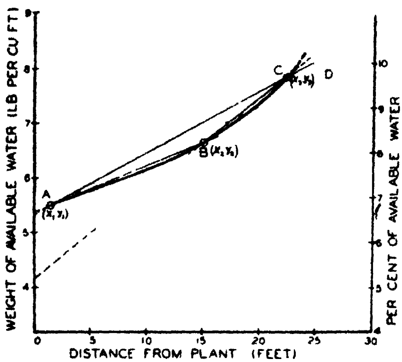

FIG. 1.—Increase in available water with distance from a plant.

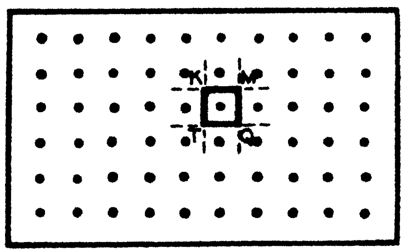

FIG. 2.- Spacing of plants giving water availability as squares

(Figs 2 and 3) from which to secure water and nutrient materials. Samples for moisture content are taken at measured distances from the plant At a given distance, q_1 feet, the percentage of water is $P_1(=P_1'=P_1''$ etc.). At q_2 feet further from the plant there is $P_2(=P_2'=P_2''$ etc.) per cent of water. P_2 is greater than P_1 because the samples are taken at a greater distance where there is a lower root concentration. Still other samples might be taken at q_3 feet farther from the plant. This is the way in which the percentage data were obtained for Table 1 and Fig. 1.

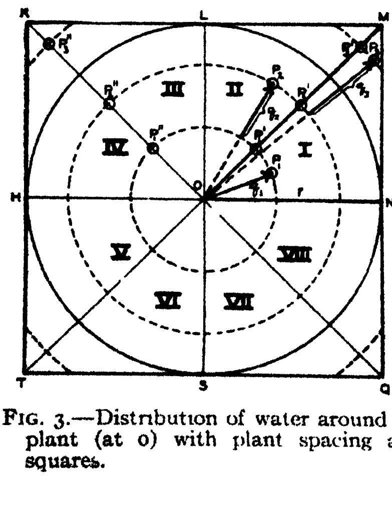

FIG. 3.—Distribution of water around a plant (at o) with plant spacing as squares.

Polar coordinates are more suitable than rectangular coordinates in solving this problem in which the moisture is assumed to increase uniformly from a center (or radially). Instead of the usual ordinates and abscissas (vertical and horizontal), the position of any point is defined as a certain distance f from the point of origin, O, measured at an angle ϕ from the horizontal base line ON (Fig. 4). Any point in a plane is defined by giving its two coordinates f and ϕ.

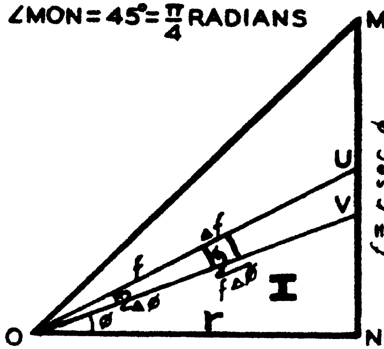

FIG. 4 -Segment *mon* taken from Fig 3, showing integration process with polar coordinates

In a right triangle such as NOV

$$\text{secant } \phi = \frac{\text{hypotenuse}}{\text{side adjacent angle } \phi} = \frac{OV}{ON}; \text{ and } OV = ON \text{ secant } \phi$$

Since ON = r and OV = f, the equation for line MN, in polar coordinates, is

$$f = r \sec \phi \tag{12}$$

Since the moisture content increases with distance uniformly about the plant, only a portion of the area from which moisture is drawn needs to be considered in the integration. The distribution of moisture in MON (Figs 3, 4) is repeated eight times about the plant. Angle MON is 45° or $\frac{\pi}{4}$ radians, while ON = r is half the distance between plants in a row. The following application of calculus evaluates the amount of water contained in the soil volume represented by the area of triangle MON in a stratum of 1 foot thickness

Calculus is designed to give the summation for the whole area MON of all the small units of water contained in corresponding small units of soil, any one of which is represented by the small rectangle in Fig. 4. The sides of the rectangles become infinitesimally small and the number of rectangles increases infinitely. The rectangle is the upper base of a prism of soil 1 foot high. The dimensions of the small unit of soil are unity, Δf, and $f \times \Delta\phi$ in which f is expressed in feet and angle ϕ is expressed in radians. The small amount of water ΔW in this unit of soil is dependent on its volume and its distance from the plant, that is,

$$\Delta W = F(f) \times \text{volume of unit} = F(f)\, f\, \Delta f\, \Delta\phi \tag{13}$$

in which F (f) is the function of f expressing the relationship between water content of the soil and distance from the plant. This relationship was shown to be $y = mx + b$ when m and b were expressed in appropriate units as in equations (10) and (11). This equation may be written as a function of x: $F(x) = mx + b$ and since x may signify distance from the plant in any direction, as does f,

$$F(f) = mf + b \tag{14}$$

For convenience the values of m and b in terms of soil moisture constants are not substituted until after integration.

Substituting the value of F (f) from equation (14) in (13),

$$\Delta W = (mf + b)\, f\, \Delta f\, \Delta\phi \tag{15}$$

Recalling that the total water (W) available to the plant is 8 times the amount in triangle MON, and that the triangle (Fig. 4) is bounded by the line MN whose equation (12) is $f = r \sec \phi$, and lines OM and ON (the values of f at $\phi = 0$ and $\phi = 45°$), we may write,

$$W = 8 \lim_{\substack{\Delta f \to 0 \\ \Delta\phi \to 0}} \sum_{\phi_1 = 0}^{\phi_2 = 45°} \sum_{f_1 = 0}^{f_2 = r \sec \phi} (mf_2 + b)\, f\, \Delta f\, \Delta\phi$$

In the limit, differential quantities are used, and

$$W = 8 \int_{\phi_1 = 0}^{\phi_2 = 45°} \int_{f_1 = 0}^{f_2 = r \sec \phi} (mf + b)\, f\, df\, d\phi = 8 \int_0^{45} \int_0^{r \sec \phi} (mf^2 + bf)\, df\, d\phi \tag{16}$$

When equation (16) is integrated (1) first with respect to f, and then ϕ

$$W = 8 \int_0^{45°} \left[\frac{mf^3}{3} + \frac{bf^2}{2} \right]_0^{r \sec \phi} d\phi = 8 \int_0^{45°} \left[\frac{mr^3 \sec^3\phi}{3} + \frac{br^2 \sec^2\phi}{2} \right] d\phi$$

$$= \frac{8mr^3}{3} \int_0^{45°} \sec^3\phi\, d\phi + \frac{8br^2}{2} \int_0^{45°} \sec^2\phi\, d\phi$$

$$W = \frac{8mr^3}{3 \times 2} \left[\sec \phi \tan\phi + 2.303 \log_{10}(\sec\phi + \tan\phi) \right]_0^{45°} + 4br^2 \left[\tan\phi \right]_0^{45°} \tag{17}$$

$$= \frac{4mr^3}{3} (\sqrt{2} + 2.303 \log_{10} 2.414) + 4br^2 = \frac{4mr^3}{3} (1.414 + 0.881) + 4br^2$$

$$W = \frac{4 \times 2.295}{3} mr^3 + 4br^2 \tag{18}$$

The amount of water in the plat taken as an example is calculated from equation (18) as follows: In equation (5) and (6), $m_1 = 0.0842$ and $b_1 = 5.39$. Taking 30 feet as the distance between plants, or $r = 15$ feet,

$$W = \frac{4 \times 2.295}{3} \times 0.0842 \times (15)^3 + 4 \times 5.39 \times (15)^2 = 5{,}720 \text{ pounds.} \tag{19}$$

This means that there are 5,720 pounds of water in the 1-foot section of earth, 30×30 feet in area, for which the moisture percentages were known. Equation (18) is transformed into more readily usable forms in following paragraphs.

GENERAL FORMULAS FOR ANALYSIS OF FIELD DATA

Equation (18) above gives the relationship between the plant distribution (r), water distribution (m, b) and the available water present (W).

$$W = \frac{4 \times 2.295}{3} mr^3 + 4br^2$$

Substituting from equations (10) and (11) the values of m and b expressed in terms of soil moisture constants,

$$W = \frac{4 \times 2.295}{3}\left[\frac{\text{Vol.wt} \times 62.43}{100}\,\frac{P_2 - P_1}{q_2}\right] r^3 + 4\left[\frac{\text{Vol.wt.} \times 62.43}{100}\left(P_1 - \frac{(P_2 - P_1)q_1}{q_2}\right)\right] r^2$$

$$W = \frac{4 \times 2.295 \times 62.43}{3 \times 100} \times \text{Vol wt.} \times r^3\,\frac{P_2 - P_1}{q_2} + \frac{4 \times 62.43}{100}$$
$$\times \text{Vol. wt.} \times r^2 \times \left[P_1 - \frac{(P_2 - P_1)\,q_1}{q_2}\right]$$

$$\mathbf{W = 1.9104 \times Vol.\ wt. \times r^3 \left[\frac{P_2 - P_1}{q_2}\right] + 2.4972 \times Vol.\ wt. \times r^2 \left[P_1 - \frac{(P_2 - P_1)\,q_1}{q_2}\right]} \qquad (20)$$

P_1 = % water at q_1 distance, and P_2 = % water at $q_1 + q_2$ distance.

The volume-weight may be determined with the same samples as used for moisture determinations. In loess and similar material the volume-weight is approximately 1.30. For illustrative purposes the spacing of plants in the row is taken as 30 feet between centers. Then r is 15 feet. Substituting in equation (20),

$$W = 1.9104 \times 1.30 \times (15)^3\,\frac{P_2 - P_1}{q_2} + 2.4972 \times 1.3 \times (15)^2 \left[P_1 - \frac{(P_2 - P_1)\,q_1}{q_2}\right]$$

$$W = 8382\,\frac{(P_2 - P_1)}{q_2} + 730.4\left[P_1 - \frac{(P_2 - P_1)\,q_1}{q_2}\right] \qquad (21)$$

This simplified form of the equation applies to a whole field of a given spacing, and the weight of water for a given plant (or hill) in a 1-foot section of earth is computed from the percentages of water at known distances from the plant. In Table 1, $P_1 = 6.8\%$, at $q_1 = 1.5$ feet from plant, and $P_2 = 8.2\%$, at $q_2 = 13.5$ feet further from the plant. These data substituted in equation (21) give

$$W = 8382\,\frac{8.2 - 6.8}{13.5} + 730.4\left[6.8 - \frac{(8.2 - 6.8)}{13.5} \times 1.5\right] \qquad (22)$$

The quantity $\dfrac{P_2 - P_1}{q_2} = \dfrac{8.2 - 6.8}{13.5} = 0.1037$ may be substituted twice in evaluating (22):

$$W = 8382 \times 0.1037 + 730.4\,(6.8 - 0.1037 \times 1.5) = 5720 \text{ pounds} \qquad (23)$$

This is the weight of water in a 1-foot section of 30×30 foot area, which is the same value as in equation (19).

APPLICATION OF THE FORMULAS TO MOISTURE DATA

In order to obtain the total amount of available water in a 25 or 30 foot section of earth through which tree roots penetrate, or in a shallower section for most other plants, several of the following steps would be taken. A plot of the moisture data is drawn such as illustrated in Fig. 5. The moisture percentages may conveniently be plotted on the horizontal axis and depth on the vertical axis. The hygroscopic coefficient percentage may be shown at the left of the

vertical axis thus leaving at the right of the axis only available water content, on which the plant depends for its moisture supply. The second step is to divide the available water curve into regions. In some depth ranges, moisture content may not vary with distance from the plant. For example, periodic rainfall wets the surface 4 feet (region A, Fig 5); at 12 to 18 feet (region C) substantially all of the available water is gone; below 26 feet (region E) little of the available water is used. At any one of these depth ranges (regions A, C, E), the weight of water may be computed in the usual way.

$$W = \frac{\%\ \text{water}}{100} \times \text{Vol wt} \times 62\ 43 \times \text{Soil Volume} \qquad (24)$$

Volume is in cubic feet and is equal to the product of the area occupied by the plant and the depth of the region in question

Where the moisture content varies with distance from a plant (as in regions B and D, Fig. 5), the integrated equations (20) and (21) are designed to give the weight of water Considerably over one-half the available water may be used near the plant when less than one-fourth of it is used at the periphery of the area of water availability A separate substitution is ordinarily required for each foot of depth, however, for a given set of field conditions, the successive applications after one evaluation of a 1-foot section are more simple because of the repetition of several factors

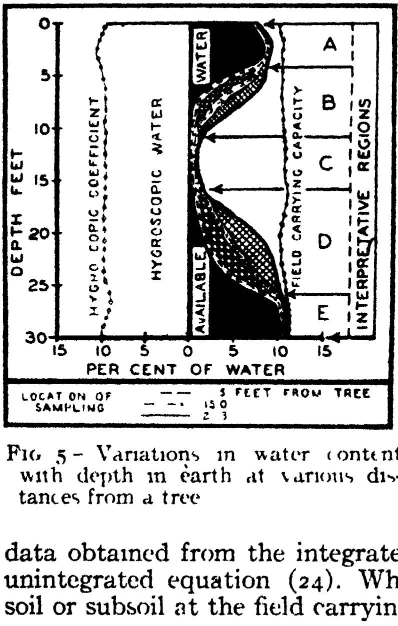

FIG 5 – Variations in water content with depth in earth at various distances from a tree

The following equations are useful in interpreting the moisture data obtained from the integrated equations (20) and (21) and the unintegrated equation (24). When W_F is the water contained by soil or subsoil at the field carrying capacity (FCC),

$$W_F = \frac{\text{FCC}}{100} \times \text{Vol wt} \times 62\ 43 \times \text{Soil Volume}$$

Soil volume is expressed in cubic feet. Similarly unavailable water W_U, is expressed by

$$W_U = \frac{\text{H C}}{100} \times \text{Vol wt} \times 62\ 43 \times \text{Soil Volume}$$

in which H.C. is the percentage of unavailable water (2). Then available water W_A present in a soil or subsoil at its field carrying capacity is expressed as $W_A = W_F - W_U$. In previous equations, W is obtained in terms of available water present when the moisture data used are percentages of available water, i.e., total per cent water

minus the hygroscopic coefficient. If the original subsoil-moisture content was the field carrying capacity, then the proportion of the originally available water already used by plants at the time of sampling is expressed by the following:

$$\text{Per cent of the available water remaining} = \frac{W}{W_A} \times 100 \qquad (25)$$

MODIFICATIONS OF THE FORMULAS FOR OTHER UNITS AND MOISTURE DISTRIBUTION

UNITS

For sampling depth-intervals of 2, ½, ⅓, or other factors of a foot, equations (20) and (21) are evaluated as previously discussed and the results are multiplied by 2, ½, ⅓, or other factors of a foot used in sampling. Units other than feet and pounds may be used by modifying the numerical constants in equation (20).

MOISTURE DISTRIBUTION

The water content does not increase exactly in proportion to distance from the plant as shown by the curve formed by the three points. A closer approximation is obtained by averaging the value found in equations (19) or (23) with that obtained by the use of a third moisture percentage P_3 at C (Fig. 1). This involves the use of line AC with slope and intercept determined in equations (8) and (9). The coordinates for $A(x_1y_1)$ and $C(x_3y_3)$ from Table 1 are substituted into equation (21). The sampling distances in this case are feet from o to P_1 and from P_1' to P_3' (Fig. 3), thus q_2 in the equation is replaced by q_2+q_3.

$$W = 8382\,\frac{P_3 - P_1}{q_2+q_3} + 730.4\left[P_1 - \frac{(P_3-P_1)\,q_1}{q_2+q_3}\right]$$

$$W = 8382\,\frac{9.7-6.8}{2.3+1.5} + 730.4\left[6.8 - \frac{9.7-6.8}{2.3+1.5}\times 1.5\right] = 5{,}982 \text{ pounds} \qquad (26)$$

Taking the average of significant figures, $\dfrac{5980+5720}{2} = 5{,}850$ pounds of water. (27)

This represents the evaluation of equation (21) for the mean line AD (Fig. 1).

The curve ABC may be approximated along lines AB and BC (Fig. 1) as follows when OP_2 (Fig. 3) is less than r: The values m and b for line BC are first calculated from $B(x_2y_2)$ and $C(x_3y_3)$, and the amount of water (W_{BC}) is obtained by the use of equation (18). The amount of water (W_1) in a circle of radius OP_2 (Fig. 3) is found using these same values of m and b, by equation (34) explained below. The distance OP_2 is the value of r_3. The amount of water (W_2) in the circle of radius OP_2 is next calculated using equation (34) with the values of m and b for line AB computed for points $A(x_1y_1)$ and $B(x_2y_2)$. Whence, the water content, W, of KMQT, based on lines AB and BC, is

$$W = W_{BC} - W_1 + W_2 \qquad (28)$$

The weight of water may be estimated more closely if the equation of the curve ABC is found analytically. The equation would give y as another function of x or f, as

$$y = F'(x) = F'(f) \tag{29}$$

This new function, F′ (f) could be substituted in equations (13) and (16) and integrated, though possibly with some difficulty.

Water content increases slightly more rapidly toward M than toward N in Fig. 4 because the surrounding plants are further from the line OM than the line ON. Further sampling would permit the analytical expression of water content as a function of distance from the plant and angular rotation ϕ from the line ON, thus $W = F''(f,\phi)$. This expression might be substituted for F (f) in equations (13) and (16) and its integration would give a still more exact expression of water content. It is believed that relative errors in sampling and other manipulations would make such exhaustive mathematical application impracticable.

MODIFICATIONS FOR PLANT SPACINGS

SQUARES

The integration is based on arrangement of plants in the form of squares, and this is a common arrangement. Brief consideration is now given to two other possible plant arrangements and the method of obtaining water content for the simplest case in which the water increase is proportional to the distance from the plant

RECTANGLES IN GENERAL

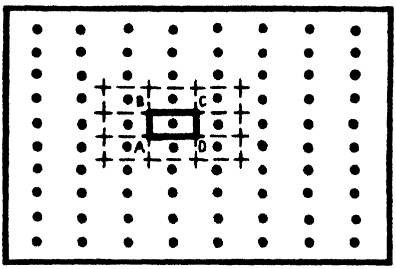

FIG. 6.—Spacing of plants with greater distance between rows than between plants in a row, giving water availability as rectangles (not squares).

The case may arise when space between plants in the row is less than the space between the rows (Fig. 6). Each plant may draw moisture from the area ABCD (Figs. 6, 7). The available water remaining may be computed from modified forms of the integrated equation (17). The weight of water, W, is obtained as two sums, W_I corresponding to the water in the four areas labeled I, and W_{II} corresponding to that in the four areas labeled II (Fig. 7). The situation is as follows:

$$W_I = \tfrac{1}{2} \times \left[\text{equation (17) evaluated for } r_1 \text{ and angle } \phi_1 = 0,\ \phi_2 = COE\right] \tag{30}$$

$$W_{II} \times \tfrac{1}{2} \times \left[\text{equation (17) evaluated for } r_2 \text{ and angle } \phi_1 = 0,\ \phi_2 = COH\right] \tag{31}$$

Total water, W, in ABCD is

$$W = W_I + W_{II} \tag{32}$$

The values for r_1, r_2 and angles COE and COH are found for a given field by the inter-row and inter-plant distances as indicated in Fig. 7. The numerical values of logarithms, tangent ϕ, and secant ϕ are given in tables (3).

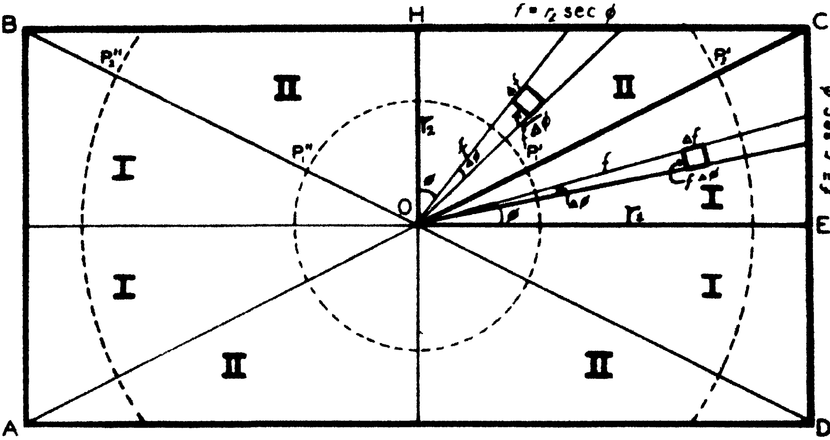

FIG. 7.—Method of applying formula for water content with rectangular (not square) spacing of plants.

HEXAGONS AND OTHER FIGURES APPROACHING CIRCLES

In the arrangement of plants shown in Fig. 8, the distance between plants in a row is equal to the distance between the rows. Each plant

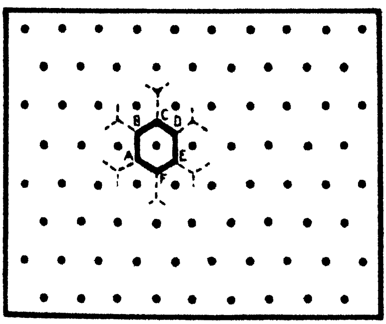

FIG. 8.—Alternate plant spacing, giving water availability as hexagons.

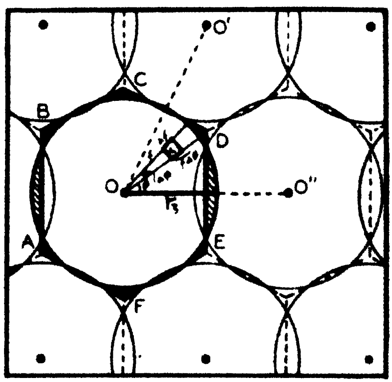

FIG. 9.—Circle approximation of hexagonal area and integral limits for water content.

has the hexagonal space ABCDEF from which to draw moisture. A circle of radius r_3 (Fig. 9), having the plant at o as its center, has an area equivalent to the area of the hexagon. The water content W is found by integration of an equation set up exactly as in equation (16)

except that the limits are the circle $f_1 = 0$, $f_2 = r_3$ and $\phi_1 = 0$, $\phi_2 = 360° = 2\pi$ radians:

$$W = \int_{\phi_1=0}^{\phi_2=2\pi} \int_{f_1=0}^{f_2=r_3} (mf+b)\, f\, df\, d\phi = \int_0^{2\pi} \left[\frac{mr_3^3}{3} + \frac{br_3^2}{2} \right] d\phi \tag{33}$$

$$W = 2\pi \left[\frac{mr_3^3}{3} + \frac{br_3^2}{2} \right] \tag{34}$$

in which m and b are defined by equations (16) and (11) and r_3 is $0.505 \times$ line oo′ or $0.565 \times$ line oo″ (Fig. 9). These ratios for r_3 were computed as follows: The area of the hexagon was determined from the geometry of a plot on graph paper; the radius r_3 of a circle having this area was computed; and the ratios

$$\frac{r_3}{oo'} = 0.505 \text{ and } \frac{r_3}{oo''} = 0.565 \tag{35}$$

were then taken.

SUMMARY

In certain orchard, lysimeter, and other moisture studies, the water content of soil and substrata is not uniform but varies systematically. The calculation of the weight of water in soil or subsoil materials in which the water content varies with distance from a plant is considered. Formulas are derived by a procedure analogous to that used in deriving the formula for the area of a circle. The use of the formulas requires the use of simple arithmetic only.

Three possible arrangements of plants are considered. With plants arranged in checker-board fashion, i.e., as squares, the weight of water available to each plant in a given foot of depth is approximated closely by formula (20). A condensed formula for a given field may be prepared according to the illustrative formula (21). A separate substitution is usually required for each foot or other individual sampling depth. These formulas are not required, of course, in any sampling depth ranges in which water content does not vary with distance from the plant.

With plants arranged with more space between rows than between plants in a row, equations (30), (31), and (32) are used. Tables must be consulted for evaluating the constants for a given field, after which calculations are easily carried out. In alternate plant spacing with inter-plant and inter-row distances approximately equal (Fig. 8), the formula (34) is used.

The curve in Fig 1 is an example of the increase in moisture content with distance from a tree. The derivations take into account the increasingly greater amounts of soil volume corresponding to the moisture content at sampling positions successively further from a plant. A simple average moisture content for the whole area would not take this into account, nor can a satisfactory approximate weighted average be obtained. The assumptions made in the derivations, on the other hand, give an aggregate error of but a few per cent at most.

LITERATURE CITED

1. GRANVILLE, W. A., SMITH, P. F., and LONGLEY, W. R. Differential and Integral Calculus. Boston:Ginn and Co. 1934. (Pages 1–3, 225, and 512.)
2. KIESSELBACH, T. A., RUSSEL, J. C., and ANDERSON, ARTHUR. The Significance of Subsoil Moisture in Alfalfa Production. Jour. Amer. Soc. Agron., **21**:241–268 1929.
3. HODGMAN, C. D., and LANGE, N. A. Handbook of Chemistry and Physics. Cleveland:Chemical Rubber Pub. Co.
4. WIGGANS, C. C. The Effect of Orchard Plants on Subsoil Moisture. Proc. Amer. Soc. Hort. Sci., 33:103–107. 1935.
5. ——— Some Further Observations on the Depletion of Subsoil Moisture by Apple Trees Proc. Amer. Soc. Hort. Sci., 34:160–163 1936.

A CRINKLED LEAF MUTATION IN ALFALFA[1]

T. E. ODLAND AND ROBERT LEPPER, JR.[2]

BREEDING work with alfalfa has been in progress at the Rhode Island Agricultural Experiment Station for the past 10 years. In another paper[3] the methods and materials used and some of the results obtained in the study of flower color inheritance have been presented. Among other strains, selections, and hybrids obtained from various sources was an F_1 hybrid obtained from the Cornell Experiment Station. This cross was studied by Moe[4] at British Columbia and at Cornell University. The hybrid resulted from a cross between *M. sativa* and *M. falcata*.

In this hybrid an abnormality in the F_2 occurred which causes a crinkling of the leaf (Fig. 1). In this abnormality the leaf appears puckered and the margin has an irregular conformation due to an extension of tissue at the periphery. The abnormality was apparently brought about by the epidermis and mesophyll growing at a more rapid rate than the vascular tissue. The presence of a large amount of crinkled leaf was detrimental to the plant and resulted in stunted growth and a very limited production of flowers or seed.

The crinkled condition was not apparent in the F_1 generation. An F_2 progeny of 418 plants, 244 were normal, being without crinkle, and 174 plants had varying degrees of it (Fig. 2). Comparison of the observed and the calculated data, as shown below, suggests a trifactorial basis for this character:

	Normal	Crinkle	Total
Observed	244	174	418
Calculated	242	176	418
Difference	+2	—2	0

A difference of 2 with a probable error of 7 indicates the closeness of the fit.

Complementary dominant factors D and E are assumed to be present in the normal plant. It is suggested that the absence of one or the other produces the crinkled character. Dominant Cr produces crinkle except in the presence of D and E. The triple recessive also results in normal plants. On this basis, the genetic makeup of two normal-appearing parents for the crinkled leaf condition could be DDEECrCr and ddeecrcr. In the F_2 a 37:27 ratio of normal to crinkle would be expected. In the cross studied it appears probable that the mutation from cr to Cr occurred in the F_1.

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[1]Published by permission of the Director of Research, Rhode Island Agricultural Experiment Station, Kingston, R. I. as contribution No. 534. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1938. Received for publication November 23, 1938.

[2]Agronomist and Former Graduate Assistant, respectively.

[3]LEPPER, R. JR., and ODLAND, T. E. Inheritance of flower color in alfalfa. Unpublished data.

[4]MOE, G. G. Alfalfa studies. A preliminary study of the inheritance of certain morphological characters. Unpublished thesis, Cornell University. 1928.

The crinkled condition existed in varying degrees in those plants which possessed the character. The occurrence of the several degrees of crinkle might be explained as the result of the influence of a number of modifying factors that were present in varying amounts in these plants.

The behavior of F_3 families (Table 1) grown from plants with no crinkle, little crinkle, medium crinkle, and much crinkle is difficult to explain. Ten genotypes which are phenotypically crinkled and would allow only for the production of crinkled

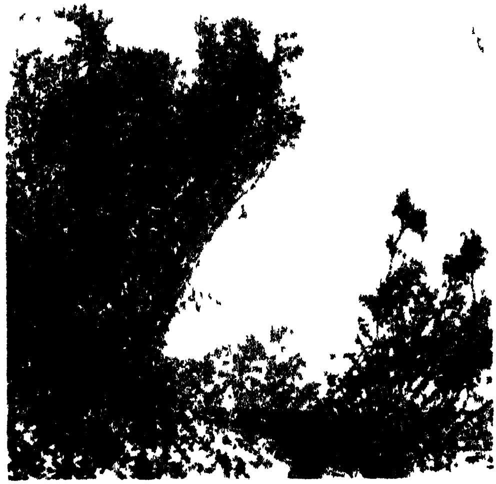

FIG. 1. Normal plant, left, and crinkled leaf plant, right.

FIG. 2. Degrees of crinkled leaf in alfalfa (F_2 20).

TABLE 1. *Segregation for crinkled leaf in F_3 families*

Degree of crinkle in the F_2	F_3 generation	Normal 0	Crinkle 1-9	Combined numbers
0	F_3 20 3	20		
	F_3 20 5	12		
	F_3 20 6	5		44 normal
	F_3 20 8	5	1	1 crinkle
	F_3 20 13	2		
1	F_3 20 1	9	7	28 normal
	F_3 20 9	2	1	8 crinkle
	F_3-20 2	17		
5	F_3 20 4	2		19 normal
	F_3-20 10	5	7	24 crinkle
	F_3-20 11	12	17	
9	F_3-20-7	.	1	7 normal
	F_3-20 12	7	15	16 crinkle

progeny are theoretically possible. It is assumed that those plants which have crinkle to a large degree and which would produce only crinkle in their progenies fail to produce seed. The crinkled plants that do produce seeds would be those types which segregate for both crinkle and normal.

According to theory, nine possible genotypes with normal expression exist which may segregate and four which may not. As Table 1 shows, those progenies grown from selfed F_2 plants possessing no crinkle produced only normal plants except in one case This may be attributed to the fact that the progenies were small and crinkled individuals which should appear in the minority have consequently not appeared.

The fact that large numbers of crinkled individuals appear in proportion to normal plants, as the parent ranges from normal to much crinkle, suggests the possibility that various degrees of crinkle depend upon the genotypes and the individual factors involved.

THE RELATIONSHIP BETWEEN THE ORIGIN OF SELFED LINES OF CORN AND THEIR VALUE IN HYBRID COMBINATION[1]

SHAO-KWEI WU[2]

MODERN methods of corn breeding are characterized by the development of inbred lines and their use in hybrids. Extensive studies have been made of methods of breeding improved inbred lines and of prediction of the probable yielding ability of inbred lines in commercial hybrids on the basis of their combining ability with other inbred lines used as testers, or their combining ability in top crosses The primary purposes of many of these studies were to find some method of discarding undesirable inbreds at as early stage as possible and the development of the best yielding inbreds that combine well in crosses

In the past there have been very few controlled studies of the relationship between hybrid vigor and the origin of the inbred lines. It is the purpose of this study to present experimental results on the combining ability of inbred lines in single crosses in relation to the genetic origin of the lines.

Publications concerning the modern method of corn breeding are voluminous and have been reviewed extensively by Hayes, Hayes and Garber, Jenkins, and Richey [3] The reader is referred to these papers for a comprehensive review of the subject.

MATERIAL AND METHOD

The inbred lines used were furnished by the Division of Agronomy and Plant Genetics, University of Minnesota, and were especially favorable ones for a study of combining ability in relation to their origin. They were obtained by the pedigree method of breeding by selfing after crosses were made among the parental inbred lines in such a way that at least one of the parents in each cross had considerably more than average ability to withstand lodging. The resulting lines, produced by selfing for six or more generations after the crosses were made, were rather outstanding in ability to withstand lodging. These lines were homozygous

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1661 of the Journal Series, Minnesota Agricultural Experiment Station. Part of a thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy at the University of Minnesota. Received for publication November 23, 1938.

[2]The recipient of the Anhwei Provincial Research Fellowship, Anhwei, China. The writer wishes to express his sincere appreciation to Dr. H K. Hayes, under whose direction this study was made, to Dr. I. J. Johnson for his advice regarding many phases of the field work, and to Dr. F. R. Immer for advice regarding the analysis of the data.

[3]HAYES, H. K. Methods of plant breeding. Nat. Agr. Res. Bureau, Nanking, China. 1937.

HAYES, H. K., and GARBER, R. J. Breeding Crop Plants. New York: McGraw-Hill Book Co. Ed. 2. 1927.

JENKINS, M. T. Corn improvement. U. S. D. A. Yearbook, 1936: 455–522. 1936.

RICHEY, F. D. Corn breeding. U. S. D. A. Bul. 1489. 1927.

for yellow endosperm, appeared to be relatively vigorous, and had desirable seed and plant characters. The origin of the inbred lines used in making crosses for this study is given in Table 1.

TABLE 1.—*Origin of inbred lines of corn.*

Group	Original parental lines crossed	Culture number of the resulting inbred lines	Years selfed
I	49 x 9-29	160, 166, 168, 177, 185, 192, 197	6
II	15-28 x 8-29	232, 234, 239, 243, 245, 246	6
III	15-28 x 9-29	253, 260, 266, 275, 279, 283, 292, A-136	6
IV	43 x 47	A-157, A-158, A-162, A-163	8
V	49 x 64	A-89, A-90	6
VI	64 x H	A-96	6
VII	15-28 x H	A-147	6

Parental inbred cultures 43, 47, and 49 were obtained from Minn. No. 13, 64 was selected from Northwestern Dent, 15-28 from Rustler White Dent, H from Reid's Yellow Dent, 8–29 from Purdue Early Yellow Dent, and 9-29 from Osterland's Yellow Dent.

In 1935, single crosses were made between the inbred lines in the first three groups with reference to the original parental inbred lines from which the present inbred lines were obtained. The plan of crosses was as follows:

1. A set of single crosses, which will be later designated as group A, were made between the inbred lines produced from single crosses with both parents in common, i.e., by making all possible intercrosses between inbred lines within group I as shown in Table 1
2. Single crosses, later designated as group B, were made between inbred lines with one parent in common, i.e., between each inbred line in group III with three lines in group II, although not with the same three lines in each case
3. Single crosses, later designated as group C, were made between inbred lines with no parent in common, i.e., between each line in group I with any three lines in group II.
4. Inbred lines of each group were also crossed with Minnesota No 13, an open-pollinated variety used as the male parent in the top crosses.

Yield trials were made in 1936 at University Farm, St. Paul, and in Meeker County, Minnesota. Randomized block arrangements were used in the yield trials, each group of single crosses and three checks being considered as a unit. Within a group there were three replications, using single row plats of 12 hills for each variety and cross. Three check varieties, namely, Minnesota No. 13, an adapted strain for Central Minnesota, and Minhybrids 401 and 402, the double crosses released by the Minnesota Agricultural Experiment Station for central Minnesota, were included and randomized with the crosses in each block.

At maturity, nly hills with three stalks surrounded by hills with corn were harvested. Green weight of ears from each plat was taken in the field. Ears of each plat were put in a cloth bag and oven dried at University Farm to place yields on a dry matter basis and determine moisture content at harvest. Yields in bushels per acre were calculated on a 14% moisture basis.

Unfortunately, the summer of 1936 was unusually dry so that the trials planted in Meeker County only were harvested. Since the data obtained that year merely consisted of one complete set of crosses planted in Meeker County, the trials were repeated in 1937 at University Farm, St. Paul, at the branch experiment station at Morris, and in Meeker County. Seed for certain crosses in each of the

three groups was insufficient for the 1937 yield trials. Crosses of a similar nature made by the Division of Agronomy amd Plant Genetics were kindly furnished to the writer so that about the same number of crosses for each type of parental origin were available in 1937 as in the previous year. The origin of inbred lines used in these crosses is given in Table 1 as groups IV, V, VI, and VII. The data of the single and top crosses obtained from University Farm in 1937 were later discarded on account of drought.

The inbred lines and original parental inbred lines were also planted at University Farm from 1935 to 1937, inclusive, in duplicated, randomized, single-row plats in single plant hills 1 foot apart in the row. Measurements for different characters were taken each year.

EXPERIMENTAL RESULTS

STUDY OF CHARACTERS OF INBRED LINES OBTAINED BY CROSSING TWO PARENTAL INBREDS FOLLOWED BY SELECTION

Since the inbred lines were obtained by the pedigree method of selection after crosses were made between the original parental inbreds, it should be interesting to study the actual effects of this method in the improvement of the inbreds In order to study differences between the inbred lines, the analyses of variance were calculated by the methods devised by Fisher[4] Tests of significance to determine whether or not there were significant differences between the parents and their progenies and among the progenies themselves were made by reference to tables provided by Snedecor.[5] In Table 2 are given the means and the range of variability for each character studied, grouped according to the origin of the resulting lines. The F values are presented in Table 3

The inbred lines varied significantly in each of the three trials in all but 2 of the 11 characters studied, namely, root volume in 1935 and percentage of smutted plants in 1935. In general, the means of the resulting lines were between the limits of the two parental inbred lines. In some instances, and for some characters, the selected lines exceeded the limits of the more desirable parental inbred and in a few cases significantly so.

Eleven of the progeny lines were earlier numerically, as shown by date of silking, and six, as shown by date of pollen shedding, than the earliest parental lines, and four for each character were significantly so. No progeny line was significantly later than its later parent. Apparently, selection for earliness was practiced during the six generations of inbreeding and such selection was successful. The recovery of early maturing lines from the crosses of 15-28 and 8-29, early and late parental lines, respectively, clearly shows the effect of selection for this character.

Pulling resistance of the plants in culture 283 in the cross of 15–28 and 9–29 exceeded both parents significantly. This fact is interesting in view of the fact that one of the parents, culture 9–29, had been selected originally as very resistant to lodging. With this one excep-

[4]Fisher, R. A. Statistical Methods for Research Workers. London: Oliver & Boyd. Ed. 6. 1936.

[5]Snedecor, G. W. Statistical Methods. Ames, Iowa: Collegiate Press, Inc. 1937.

TABLE 2.—*Means and ranges of variability of different characters of parental inbred lines and their progenies grown in replicated plats at University Farm, 1935–1937.*

Parental inbreds and progeny lines	No. of lines	Date of silking, July		Date of pollen shedding, July		Plant height, in.		Leaf area, sq in.		Pulling resistance, lbs.		Root volume, c.c.	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
49	1	26.9		24.0		36.4		51.8		135.1		1,993.2	
8–29	1	41.2		38.7		55.2		78.8		338.0		6,737.8	
9–29	1	31.2		29.7		47.2		55.4		214.8		4,880.9	
15–28	1	31.1		27.3		34.5		62.1		139.6		3,829.9	
49x9–29	7	27.9	22.0–30.7	25.7	21.5–29.7	40.8	31.7–47.9	55.4	45.6–63.9	155.6	115.6–207.0	3,490.3	1,837.4–4,890.3
15–28x8–29	6	30.0	26.2–34.3	27.1	23.7–31.7	45.2	37.0–50.1	63.0	55.3–75.3	175.6	146.4–202.2	3,669.8	2,482.8–5,568.0
15–28x9–29	7	29.4	24.0–32.1	27.5	23.3–30.0	44.4	33.2–50.7	62.5	53.2–76.5	199.5	147.4–275.6	4,372.3	3,164.8–6,613.3

Parental inbreds and progeny lines	No. of lines	No. of brace roots underground		Ear height, in.		Ear length, cm.		Ear weight, grams		Percentage of smutted plants	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
49	1	25.2		11.2		9.6		54.6		15.0	
8–29	1	36.1		20.2		11.1		105.6		18.3	
9–29	1	36.7		22.9		10.8		78.8		3.0	
15–28	1	41.6		16.1		14.8		78.3		27.2	
49x9–29	7	32.6	24.2–43.3	16.2	5.8–22.9	11.3	9.0–13.8	62.5	14.4–105.2	14.2	2.9–21.4
15–28x8–29	6	32.3	26.4–41.2	18.1	11.9–22.9	12.6	10.9–13.7	65.9	59.0–76.4	24.0	6.9–54.2
15–28x9–29	7	37.6	32.6–45.0	19.3	13.6–27.4	12.8	8.0–16.4	81.2	46.6–108.6	19.2	1.0–43.6

TABLE 3.—*Analysis of variance of characters of inbred lines grown in 1935 to 1937*

Character	Year of trial	D F for cultures	F value	S E mean
Date of silking, July	1935	22	5.52**	1.59
	1936	23	7.20**	1.42
	1937	22	19.64**	0.88
Date of pollen shedding, July	1935	23	15.65**	0.78
	1936	23	4.74**	1.97
	1937	22	22.97**	0.73
Plant height, in	1935	23	15.24**	1.50
	1936	23	10.13**	2.07
	1937	22	22.34**	1.38
Leaf area, sq in	1935	23	11.86**	2.94
	1936	23	9.91**	3.10
	1937	22	9.61**	2.70
Pulling resistance, lb	1935	21	10.83**	11.81
	1936	23	7.12**	14.61
	1937	22	11.93**	19.23
Root volume, cc	1935	21	1.61	203.50
	1936	23	2.42*	707.06
	1937	22	2.56*	1 231.34
No. of brace roots underground	1935	21	3.86**	2.97
	1936	23	3.23**	4.20
	1937	22	4.32**	1.95
Ear height, in	1935	23	22.31**	1.15
	1936	23	17.54**	1.14
	1937	22	11.02**	1.06
Ear length, cm	1935	22	9.41**	1.38
	1937	22	14.38**	0.48
Ear weight, grams	1935	22	2.63*	6.13
	1937	22	8.33**	9.15
Percentage of smutted plants	1935	22	1.88	4.72
	1936	23	2.60*	8.27
	1937	22	3.42**	8.55

*Exceed the 5% level of significance
**Exceeds the 1% level of significance

tion, the other progeny lines did not reach the limit in pulling resistance of the more lodging resistant parent. All but one of the inbred lines were higher in pulling resistance than the lower parent and 13 of the 20 progeny lines gave significantly higher pulling resistance than the parent of lowest pulling resistance.

Culture 168 in the cross of 49×9–29 developed more brace roots underground than did either one of the parents. This culture was also fairly high in pulling resistance and root volume.

The progeny lines seemed to have been improved to a certain extent in smut resistance as there were 7 of the 20 progeny lines that were significantly lower in smut infection than the susceptible parent. However, none of them was significantly more resistant than the resistant parents in each group.

Culture 266 in the cross of 15–28 and 9–29 greatly exceeded either of the parents in root volume, although the parental lines, 15–28 and 9–29, were not significantly different in this character.

Six of the seven lines of the progenies from the cross of 49×9–29 produced as long or longer ears than did either parent. Culture 192 is

the only progeny in the three groups of crosses producing significantly longer ears than either parent.

With respect to ear weight, the progeny lines in the crosses of 49×9–29 and 15–28×9–29 varied in both directions beyond the limits of the two parents. Of the 14 progeny lines in these two groups, three cultures, 192, 283, and 292, produced ears significantly heavier than either parent. Culture 192 also produced significantly longer ears than either parent together with fairly good pulling resistance and root volume.

Considerable improvement was attained also for plant height in the cross of 15–28×9–29, as shown by culture 275 which exceeded the height of either parent, although this character was not particularly selected for in the course of inbreeding

COMBINING ABILITY OF INBRED LINES IN SINGLE CROSSES IN RELATION TO THE GENETIC ORIGIN OF THE LINES

The combining ability of inbred lines in top crosses can be used to determine whether the material used was of comparable value for breeding purposes. In Table 4 are given the F values of the top crosses planted in Meeker County and at Morris, 1936 to 1937, inclusive.

TABLE 4 —*Analyses of variance of the yield of top crosses planted in Meeker County and at Morris, 1936 to 1937*

Year of trial	Locality	D/F for crosses	F value
1936.	Meeker County	25	2 46**
1937	Meeker County	34	1.29
1937	Morris	33	1 67*

*Exceeds 5% level of significance
**Exceeds 1% level of significance

As shown in Table 4, there were significant differences among the top crosses planted in Meeker County and at Morris, except that planted in Meeker County in 1937.

The average yields of top crosses for the seven groups in relation to genetic origin are summarized in Table 5.

TABLE 5 *Average yield of top crosses by group in relation to genetic origin*

Group	Origin	No of crosses tested and average yield					
		No.	1936	No.	1937	No.	Av. 1936–37
			bu.		bu.		bu.
I .	49 x 9–29	7	39.0	7	47.5	7	44.2
II....	15–28 x 8–29	6	47.0	6	48.2	6	47.4
III...	15–29 x 9–29	7	44.7	8	49.7	7	47.7
IV.. .	43 x 47			4	49.3		
V...	64 x 49			2	46.0		
VI... .	64 x H			1	48.7		
VII...	15–28 x H			1	52.6		

The only wide differences noted were in Meeker County in 1936 where only three replications were used. In 1937, all groups gave rather similar yields in top crosses. Yields in the different groups were compared statistically and in 1936 the yields of top crosses in group I were significantly lower than groups II and III. It seems probable that the combining ability of inbred lines in group I was slightly lower than that of groups II and III.

The yield of single crosses in relation to their genetic origin are given in Table 6. Three check varieties were grown in randomized blocks with each group. Differences in yield within each group exceeded the 5% point and in all except two groups the 1% point

The average yields of single crosses are given in Table 7.

A summary of yields in the three groups of single crosses is given in Table 7 The single crosses in group A, on the average, consistently yielded less than their check varieties and they also yielded less than either group B or group C, whereas, the differences between groups B and C were small and of little statistical significance

The mean differences between the groups are compared in Table 8. The group differences were obtained by taking the mean yield of one group minus that of its check less the mean yield of the other group minus its check The standard error of the group difference was computed by the formula. $S.E._{diff} = \sqrt{S.E.^2_1 + S.E.^2_{(k1)} + S.E.^2_2 + S.E.^2_{(k2)}}$, where S.E. is the standard error of a mean

From Table 8 it may be noted that, on the average, single crosses between lines where both of the parents were in common (group A) yielded significantly less than where only one of the parents was the same (group B) and less than where there were no parents in common (group C) It should be mentioned, however, that there were some exceptions to this for some single crosses gave good yields even tho they were bred from the selections of a single cross.

The vigor of single and double crosses has been explained on the basis of a dominance or partial dominance of growth factors, part of which are contributed by each of the inbred parents and the accumulation of a larger number of these dominant factors in the hybrid than in an inbred parent. On this basis, it would be expected, other things being equal, that greater hybrid vigor would be obtained between inbred lines of diverse genetic origin than from lines more closely related.

As improved inbred lines are bred by any of the recognized methods of breeding, including the pedigree method as used to produce the inbred lines used in this study, by backcrossing or by convergent improvement, it will be of great value to consider the origin of the lines in relation to their combining ability in crosses. It seems reasonable, as the results of this study indicate, that better hybrids can be expected, on the average, if the inbred lines are combined in crosses in such a manner that lines of diverse genetic origin are used for each particular experimental hybrid.

It seems probable that future breeding will consist of planned crosses which enable one to breed improved inbred lines through the combination of desirable characters of two or more parents, the test

Group A*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	42.3	51.7	48.1
Minhybrid 401	45.8	64.4	57.6
Minhybrid 402	39.3	57.4	50.9
Mean	42.5	57.8	52.2
160×166	36.1	46.7	42.7
160×168	46.6	55.2	51.8
160×177	36.2	....	....
160×185	32.8	51.7	45.4
160×192	50.6	57.7	54.8
160×197	35.2	....	....
166×168	44.9	....	....
166×177	44.5	....	....
166×185	32.2	50.2	43.8
166×192	44.6	....	....
166×197	33.1	....	....
168×177	42.9	52.9	49.0
168×185	47.7	59.8	55.1
168×192	47.4	53.1	50.7
177×185	24.1	49.9	40.9
177×192	46.1	50.8	48.8
177×197	38.4	....	....
185×192	42.0	....	....
185×197		40.9	
A157×158		33.1	
A157×162		48.2	
A157×163		41.1	
A158×163		40.3	
Mean	40.3	48.8	48.3

Group B*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	24.1	54.3	43.8
Minhybrid 401	36.9	60.5	52.1
Minhybrid 402	31.1	48.8	42.5
	30.7	54.5	46.1
253×234	34.4	55.2	47.8
253×243	36.5	56.9	49.6
253×245	42.8	54.4	50.0
260×234	31.9	....	....
260×243	39.6	....	....
260×245	46.2	....	....
266×232	44.8	....	....
266×239	36.6	47.9	44.1
266×243	23.9	....	....
275×232	28.2	53.2	44.4
275×239	31.7	56.5	47.8
275×245	30.4	54.2	45.8
279×232	....	52.5	....
279×234	34.1	57.2	49.0
279×243	43.9	....	....
279×246	36.8	....	....
283×232	35.4	....	....
283×239	41.2	51.8	48.2
283×246	35.1	46.4	42.2
292×232	31.0	39.4	36.5
292×243	33.5	....	....
292×245	44.9	65.0	57.7
A147×96		49.2	
A147×136		53.7	
A 92×96		45.0	
Mean	36.3	52.4	46.9

Group C*			
Variety or cross	1936 bu.	1937 bu.	Average 1936–37 bu.
Minn. No. 13	22.4	52.1	42.2
Minhybrid 401	37.8	59.0	51.9
Minhybrid 402	30.6	54.2	46.3
	30.3	55.1	46.8
160×232	32.3	47.2	42.2
160×239	41.6	49.0	46.5
160×245	34.1	....	....
166×232	34.2	42.3	39.6
166×243	53.2	56.5	55.4
166×245	38.2	51.3	45.5
168×232	35.0	42.4	40.0
168×234	34.5	....	....
168×239	50.3	57.5	55.1
177×232	43.0	52.3	49.2
177×243	43.5	66.2	58.7
177×246	23.2	....	....
185×234	35.8	62.2	53.4
185×243	44.9	57.5	53.3
185×245	31.7	....	....
192×232	43.0	47.8	46.2
192×239	38.0	62.6	54.4
192×246	39.0	....	....
197×234	42.4	....	....
197×239	30.8	59.4	49.8
197×246	25.7	....	
A158×89		55.7	
A158×136		60.4	
A158×147		58.5	
A 92×163		56.2	
A147×89		50.7	
A147×90		22.7	
Mean	37.6	52.9	49.2

*Group A, representing a group of single crosses obtained from the crosses of inbred lines of a common genetic origin. Group B, representing a group of single crosses obtained from the crosses of inbred lines with one parentage in common. Group C, representing a group of single crosses obtained from the crosses of inbred lines with diverse genetic origin.

TABLE 7 — *Average yields of single crosses and check varieties in 1936 and 1937*

Group of single crosses and checks	N	Mean	Percentage yield of crosses with checks as 100
		1936	
Group A	18	40.3±0.86	94.9
Checks	3	42.5±2.11	
Group B	21	37.1±0.87	120.9
Checks	3	30.7±2.30	
Group C	21	37.6±1.04	124.1
Checks	3	30.3±2.74	
		1937	
Group A	15	48.8±0.66	84.4
Checks	3	57.8±1.48	
Group B	16	52.4±0.72	96.1
Check	3	54.5±1.67	
Group C	20	52.9±0.62	96.0
Checks	3	55.1±1.61	
		Average 1936-1937	
Group A	10	48.3±0.66	92.5
Check	3	52.2±1.21	
Group B	12	46.9±0.68	101.7
Checks	3	46.1±1.35	
Group C	14	49.2±0.65	105.1
Checks	3	46.8±1.41	

TABLE 8 — *Differences in yield of single crosses grouped according to origin of the inbred lines*

Differences between groups	Mean difference
1936	
A-B	8.6±3.35
A-C	-9.5±3.71
B-C	0.9±3.82
1937	
A-B	-6.9±2.44
A-C	-6.8±2.37
B-C	0.1±2.57
Average, 1936-1937	
A-B	-4.7±2.05
A-C	-6.3±2.08
B-C	-3.2±2.17

of the combining ability in top crosses, a study of all possible combinations in single crosses of inbred lines of high top cross yielding ability, using only combinations of diverse origin, and the final yield trial of these double crosses that appear most desirable on the basis of previous single cross yields.

SUMMARY

1. The inbred lines furnished to the writer, on account of their diverse origin, were especially favorable for a study of the relationship between the genetic origin of the inbreds and the combining ability in single crosses.

2. Inbred lines used in making single crosses for this study were obtained by the pedigree method of breeding. Four original parental inbred lines, 49, 8–29, 9–29, and 15–28, descending from four different varieties, were involved in making crosses in such a way that in each cross one of the parents was highly desirable in withstanding lodging and the other in certain other agronomic characters. The inbred lines are divided into three groups according to their parentage, namely, group I, inbred lines being obtained from the crosses made between the original parental inbreds, 49 and 9–29; group II from the crosses made between 15-28 and 8-29; and group III from the crosses between 15–28 and 9–29.

3. Three groups of single crosses were made in 1935. Group A consisted of single crosses made between inbred lines of a common genetic origin using all possible crosses between seven inbred lines in group I; group B consisted of single crosses made between inbred lines with one original parent in common where each of eight inbreds in group III were crossed with three inbreds in group II; while group C consisted of single crosses between inbred lines of different genetic origin, i.e., crosses were made between each line in group I and three lines in group II. Additional single crosses were made from another five groups of inbred lines making three types of crosses similar to group A, B, C, to replace some of the single crosses lost in 1936 due to the drought.

4. In order to study the effect of the pedigree method of breeding upon the improvement of the inbred lines, 11 characters were measured on the progeny inbred lines as well as the original parental inbred lines. All of these characters but two showed significant variability, as shown by the analysis of variance. In general, the progeny lines varied between the limits of the two parents.

5. Selection for certain characters by the pedigree method of breeding was effective in isolating inbred lines more desirable in these characters than either parent. This is especially noticeable in the selection for earliness. The inbred lines, in general, showed a combination of desirable characters from both parents.

6. It has been noted that the single crosses made from inbred lines selected from a single cross yielded, on the average, consistently lower than the single crosses made from inbred lines with one parent in common, or the single crosses made from inbred lines of diverse genetic origin. There was no significant difference in yielding ability between the single crosses made from inbred lines with one parent in common and those made from inbred lines of entirely different genetic origin.

EFFECT OF FERTILIZERS AND METHOD OF THEIR APPLICATION ON NODULATION, GROWTH, AND NITROGEN CONTENT OF HAIRY VETCH[1]

T. H. ROGERS AND D. G. STURKIE[2]

THE use of various winter legumes for soil improvement is becoming general in the South, especially in Alabama. Hairy vetch (*Vicia villosa*) is one of the most important of these winter legumes. In order to obtain the best results with hairy vetch it is necessary to apply fertilizers, particularly phosphate, and to inoculate the plants. In the past farmers have been advised not to apply superphosphate in contact with the inoculant as it was thought that the phosphate would injure the inoculation. It has been recommended that basic slag could be applied in contact with the inoculant. In order to study the effect of fertilizers on inoculation and growth the experiment reported herein was conducted.

PLAN OF THE EXPERIMENT

This experiment was conducted at Auburn, Alabama, on a very light, Norfol sandy soil, on which vetch or Austrian winter peas had never grown. Each treatment was replicated four times and the replications were distributed systematically over the area. There were eight tiers, each containing 20 plats 16.5 by 27 feet, or 1/100 acre. The plats were separated by 2-foot alleys. Every fourth plat received basic slag, was not inoculated, and served as a check plat. Hairy vetch was planted on September 23, 1936, at the rate of 30 pounds per acre in rows 4 feet apart making four rows per plat. The seed were disinfected with mercuric chloride. The commercial inoculant was applied according to the directions of the manufacturer. Soil inoculant was applied in the drill at the rate of 500 pounds per acre. The seed were covered immediately after planting in order to prevent any possible injury from the sun.

On half of the plats the fertilizer was applied in the drill by hand and the inoculated seed were then droppped on top of the fertilizer and covered. On the soil-inoculated plats the fertilizer and seed were distributed in the same manner as above and the inoculated soil placed on top of the fertilizer and seed.

On the other half of the plats the fertilizer was mixed with the soil by running a plow in the rows before the seed were planted.

In order to determine growth, 100 representative plants were dug from each plat on Novemner 11, 1936, and on December 13, 1936. The number of nodules were counted, the tops and roots were separated and weighed after having been dried in the oven, and then were analyzed for total nitrogen. On February 10, 1937, 100 plants were dug from each plat and the same determinations made except the nodules were not counted. On March 10, 1937, and April 10, 1937, the same determinations were made on plants from an entire row from each plat.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Authorized for publication by the Director. Received for publication November 25, 1938.

[2]Graduate Assistant and Associate Agronomist, respectively.

RESULTS AND DISCUSSION

A perfect stand was obtained on every plat at the beginning of the experiment. Thus, in no instance were reduced yields due to poor germination. Differences in the appearance of the vetch due to the various treatments were noticeable soon after the plants came up.

NODULATION AND GROWTH

The data in Table 1 show that in general there is some correlation between the number of nodules and growth The inoculated plants possessed more nodules and were much larger and healthier than the uninoculated plants. The uninoculated plants were nodulated; however, the nodules were minute and the small growth of the plants indicated that the bacteria were inefficient in fixing nitrogen. This indicates that the presence of nodules is not a sure sign that the plants are properly inoculated.

When commercial culture was used, it was found (Table 2) that basic slag did not reduce the number of nodules or growth of the vetch when applied in contact with inoculated seed. Growth was approximately 20% less when the inoculated seed were planted in contact with superphosphate and triple superphosphate than when the fertilizer was mixed with the soil prior to planting (Figs. 1 and 2). This difference was very obvious throughout the test. The superphosphate or triple superphosphate coming in contact with the inoculant caused no significant reduction in the number of nodules. Dolomite partially reduced or counteracted the injury caused by the superphosphate coming in contact with the seed (Figs. 1 and 2). The best results were obtained with all fertilizers except basic slag when the fertilizer was mixed with the soil before planting. If the seed and fertilizers are to be mixed, basic slag or superphosphate mixed with dolomite should be used.

When soil inoculant was used in contact with superphosphate, the number of nodules and growth of the plants were greatly reduced. The plants grown on plats where the superphosphate was mixed with the soil and did not come in contact with the inoculant produced 158% more growth than those grown on plats where the soil inoculant came in contact with the superphosphate. Figs. 1 and 2 show the differences in these treatments on various dates.

Commercial inoculant proved to be superior to soil inoculant especially when the inoculated seed and fertilizer were in contact. The superphosphate, when placed in contact with the inoculant and seed, was much more injurious when soil inoculant was used than when commercial inoculant was used. Vetch fertilized with 400 pounds of superphosphate applied in contact with soil inoculant produced 5 pounds of nitrogen per acre, while vetch fertilized with the same amount of superphosphate applied in contact with seed inoculated with a commercial culture produced 40 pounds of nitrogen per acre. When superphosphate was mixed with the soil before the soil inoculant was added, 14 pounds of nitrogen per acre were produced as compared with 49 pounds when commercial inoculant was used in the same manner.

TABLE 1 —*The influence of inoculation kind of fertilizer and method of application of fertilizer on the dry weight of the plants and number of nodules of hairy vetch* *

Fertilizer†	Inoculation	Total dry weight of tops and roots of 100 plants grams		Percentage of total dry weight in tops		Number of nodules per 100 plants	
		In contact	Mixed with the soil	In contact	Mixed with the soil	In contact	Mixed with the soil
Basic slag	None	8.8	12.3	49	50	97	150
None	None	6.3	6.4	40	46	4	7
None	Commercial	8.1	11.3	56	47	133	181
Basic slag	Commercial	15.6	24.5	58	50	373	362
Superphosphate	Commercial	17.5	31.0	65	66	558	550
Triple superphosphate	Commercial	14.0	22.5	64	59	457	557
Superphosphate dolomite	Commercial	25.7	35.8	67	66	659	737
Triple superphosphate dolomite	Commercial	18.4	28.1	60	60	658	576
Superphosphate muriate	Commercial	23.1	41.0	53	52	797	700
Triple superphosphate muriate	Commercial	19.9	28.1	62	60	484	433
Superphosphate muriate dolomite	Commercial	38.2	48.3	64	61	1 213	1 132
Triple superphosphate, muriate dolomite	Commercial	23.1	33.0	59	62	732	693
Basic slag muriate	Commercial	35.0	40.5	54	58	570	737
Superphosphate	Soil	7.3	25.7	38	54	100	613
None	Soil	9.1	10.5	50	45	194	290

*All figures are the averages of the first two harvests

†Phosphate applied at the rate of 64 pounds of P_2O_5 dolomite 400 pounds and muriate of potash 50 pounds per acre

TABLE 2.—*The influence of inoculation, kind of fertilizer, and method of application of fertilizer on the dry weight and nitrogen content of hairy vetch plants.**

Fertilizer†	Inoculation	Total dry weight per acre of tops and roots, lbs.		Percentage total dry weight in tops		Nitrogen content of plants							
						Tops		Roots		Total per acre, lbs.		Percentage of total that was in the tops	
		In contact	Separated	In contact	Separated	In contact, %	Separated, %	In contact, %	Separated, %	In contact	Separated	In contact	Separated
Basic slag	None	583	643	67	67	3.2	3.3	2.0	2.0	16.2	20.0	76	71
None ...	None	60	60	57	63	2.4	2.5	1.7	2.0	1.3	1.4	66	68
None.	Commercial	574	576	66	72	3.5	3.5	1.9	1.8	16.9	17.4	78	83
Basic slag	Commercial	1,556	1,499	66	70	3.8	3.4	1.3	1.6	45.6	43.2	85	83
Superphosphate ..	Commercial	1,175	1,440	82	83	3.7	3.7	2.2	2.2	40.4	49.4	89	89
Triple superphosphate	Commercial	1,415	1,792	82	86	3.5	3.7	2.5	2.3	46.7	62.1	87	90
Superphosphate, dolomite . .	Commercial	1,725	2,048	78	82	3.8	3.7	2.5	1.9	60.6	69.2	84	90
Triple superphosphate, dolomite	Commercial	1,490	1,988	83	82	3.4	3.9	2.1	2.1	46.3	70.4	85	89
Superphosphate, muriate . .	Commercial	1,734	1,887	82	86	3.8	3.9	2.3	2.6	61.4	70.5	88	90
Triple superphosphate, muriate	Commercial	1,481	1,764	86	85	3.6	3.4	2.1	2.3	50.2	57.1	91	90
Superphosphate, muriate, dolomite	Commercial	2,503	2,377	85	80	3.1	3.5	1.8	2.0	72.5	76.3	91	88
Triple superphosphate, muriate, dolomite.	Commercial	2,058	2,252	80	85	3.6	3.7	1.8	2.0	66.7	77.9	89	91
Basic slag, muriate	Commercial	2,614	2,857	74	75	3.2	3.3	1.7	1.5	72.8	81.9	84	88
Superphosphate . . .	Soil	193	499	62	75	3.0	3.1	2.0	2.3	5.0	14.3	71	81
None	Soil	491	533	73	72	3.1	3.0	2.3	2.0	14.0	14.5	79	80

*Harvested April 12, 1937.
†Phosphate applied at the rate of 64 pounds of P_2O_5, dolomite 400 pounds, and muriate of potash 50 pounds per acre

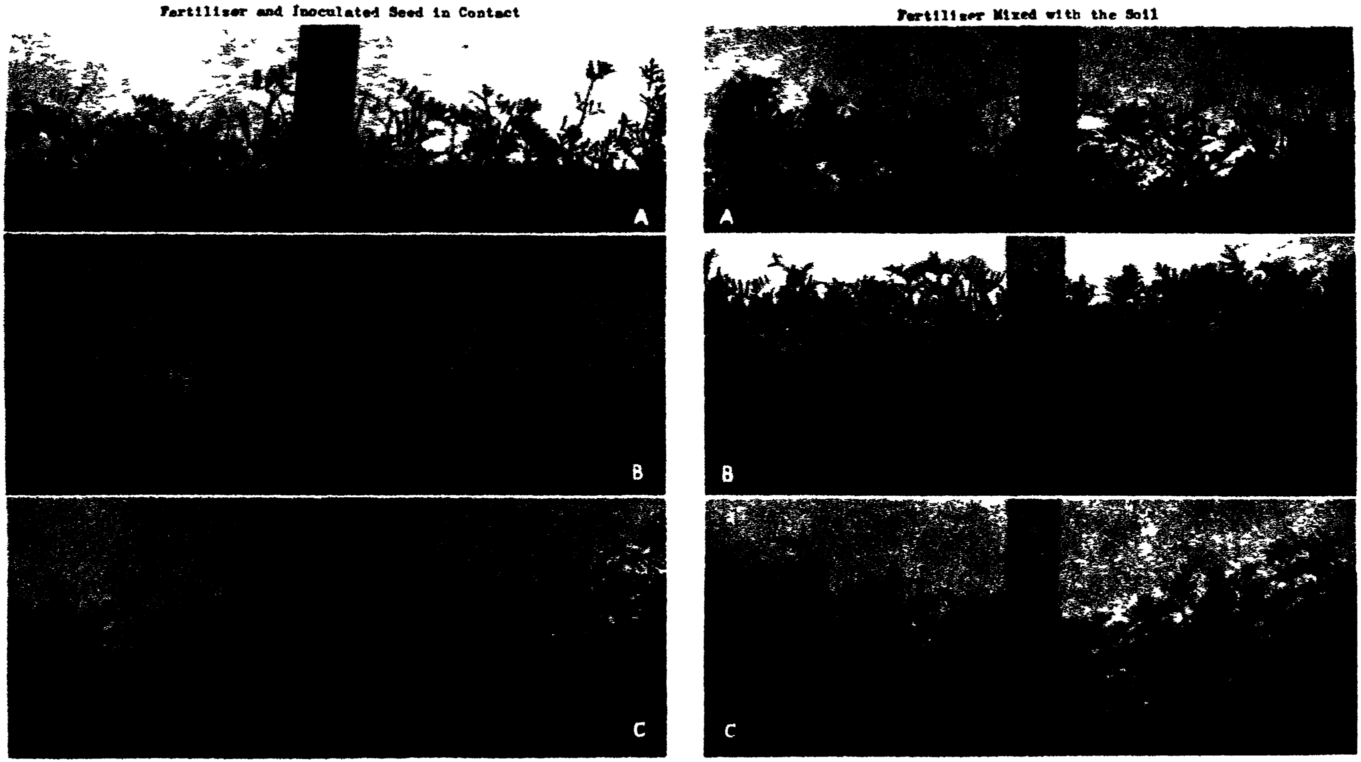

FIG. 1.—Vetch plants from different fertilizer and inoculation treatments, photographed November 10, 1936. A, superphosphate and soil inoculation; B, superphosphate and commercial inoculation; and C, superphosphate and dolomite and commercial inoculation.

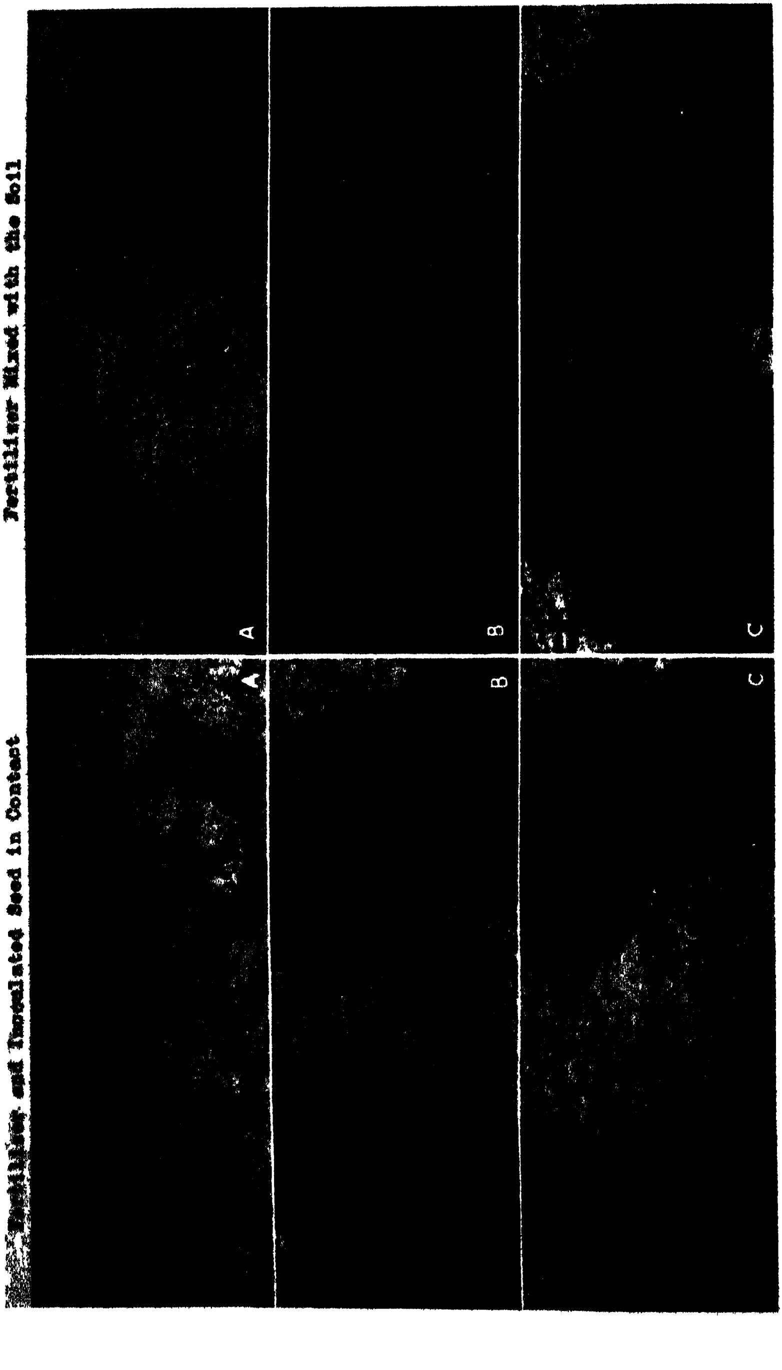

FIG. 2.—Vetch plants from different fertilizer and inoculation treatments, photographed April 12, 1937 A, superphosphate and soil inoculation; B, superphosphate and commercial inoculation, C, superphosphate and dolomite and commercial inoculation

RATIO OF TOPS TO ROOTS

From Tables 1 and 2 it can be seen that the percentage of tops increased as the vetch grew older. In general, the treatments that produced the highest yields produced the highest ratio of tops to roots.

The plants grown on uninoculated plats, soil inoculated plats, and on unfertilized plats produced a lower percentage of tops than those grown on fertilized and commercially inoculated plats. The fertilizers stimulated top growth more than root growth.

NITROGEN CONTENT

The nitrogen content of tops and of roots, total nitrogen per acre, and percentage of total nitrogen in the tops on April 12 are reported in Table 2. The unfertilized, uninoculated plants produced practically no growth and had a very low percentage of nitrogen. The fertilized and uninoculated plants produced a small growth with a medium percentage of nitrogen. The inoculated and unfertilized plants had a higher percentage of nitrogen than plants that received fertilizer without inoculation; however, the plants from both treatments produced very little growth. To get maximum growth with maximum percentage of nitrogen, both fertilizer and inoculation were necessary

The percentage of nitrogen in vetch can be increased by the proper fertilizer and inoculation treatment but there seems to be a point above which no increase could be made The nitrogen is used to increase vegetative growth rather than to increase the percentage of nitrogen in the plant. The method of application of fertilizer did not have a very marked effect on the nitrogen content of the plants.

The tops of plants receiving fertilizer and commercial inoculant contained approximately 85 to 90% of the total nitrogen. These results show the importance of turning under the entire plant in soil building. Both commercial and soil inoculation without fertilizer produced tops containing approximately 80% of the total nitrogen. Fertilizer and no inoculation produced plants with tops containing approximately 75% of the total nitrogen. The plants with no inoculation and no fertilizer produced tops with about 67% of the total nitrogen.

The method of applying the fertilizer did not greatly affect the percentage of total nitrogen in the tops except in the superphosphate and soil inoculated treatment. Mixing superphosphate with the soil before adding the soil inoculant produced tops with 81% of the total nitrogen, while the tops on the plats where superphosphate and soil inoculant were applied together contained only 71% of the total nitrogen.

CONCLUSIONS

1. The presence of nodules on the roots of vetch was not a sure indication that the plants were properly inoculated.

2. Approximately 20% less growth was produced when superphosphate and triple superphosphate came in contact with seed inocu-

lated with a commercial culture than when the fertilizer was mixed with the soil prior to planting.

3. Growth was 158% more when superphosphate was mixed with the soil before adding soil inoculant than when the superphosphate came in contact with the soil inoculant.

4. Slag or equal amounts of dolomite and superphosphate did not seriously reduce the growth when applied in contact with the inoculated seed. Dolomite partially reduced or counteracted the injury caused by the superphosphate coming in contact with inoculated seed.

5. The percentage of nitrogen in the vetch plants was increased by applications of fertilizer or by inoculation. The highest percentage of nitrogen, as well as the largest amount of vegetative growth, was obtained when both fertilizer and inoculant were used

6. The method of applying fertilizers did not affect the percentage of nitrogen in the vetch plants.

7. Commercial inoculant was only slightly better than soil inoculant when no fertilizer was used. When fertilizer was used, commercial inoculant was much superior to soil inoculant regardless of how the fertilizer was applied.

8. The ratio of tops to roots increased as the vetch grew older The treatments that produced the highest yields of vetch produced the highest ratio of tops to roots.

9. Most of the nitrogen in vetch was in the tops

LEGUME NODULE DEVELOPMENT IN RELATION TO AVAILABLE ENERGY SUPPLY[1]

FRANKLIN E. ALLISON AND C. A. LUDWIG[2]

THE causes of the variations in nodulation of legumes under more or less usual conditions of growth have been discussed by the writers in three previous papers (1, 2, 3).[3] Particular attention (3) was given to the situation where a decrease in nodulation occurs due to the presence of a liberal supply of combined nitrogen. The general conclusion arrived at was that normally under good cultural conditions the most important, but not the sole, factor in nodulation is the supply of available carbohydrate[4] reaching the nodules. In accord with this view the effect of fixed nitrogen was traced to the decrease in available carbohydrate in the roots caused by it It was further pointed out (2) that under certain conditions, such as where ineffective bacterial strains are used or where the nitrogen hunger condition occurs, carbohydrate accumulates unless fixed nitrogen is supplied and is not the limiting factor in growth Other investigators, particularly Fred and Wilson (5), have also emphasized the importance of carbohydrate supply in legume symbiosis Recently several investigators have published additional data that in our judgment confirm our previous conclusions even though some of these authors regard the carbohydrate supply explanation as inadequate. One author (17, 18) has proposed a similar but distinct and more complicated explanation to take its place. It seems well at this time, therefore, to reexamine the adequacy of our original hypothesis in the light of the new experimental data and the objections that have been raised.

The newer experimental results, like the older ones, indicate that under ordinary growing conditions, where little or no fixed nitrogen is present in the growth medium, a close correlation exists between the quantity of carbohydrate photosynthesized, on the one hand, and the extent of nodulation and nitrogen fixation, on the other. Since in this case the major interrelations are well established and have not been questioned, little further discussion of the point is necessary. Attention will be given, however, to some of the points that have been given special consideration by recent investigators.

EFFECT OF FIXED NITROGEN ON ROOT CARBOHYDRATE AND NODULATION

Considerable new evidence has been presented that supports our previous statements (1, 2, 3) to the effect that additions of fixed

[1]Contribution from the Fertilizer Research Division, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture. Received for publication December 3, 1938.

[2]Senior Chemist and Associate Plant Physiologist, respectively.

The authors are greatly indebted to Dr. Dean Burk and Mr. Francis Minor, both of this laboratory, for many helpful suggestions given during the preparation of this manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 157.

[4]The term carbohydrate is meant to include all metabolizable carbon compounds not containing nitrogen, chiefly sugars and starches, but also some organic compounds usually present in small percentages.

nitrogen that decrease nodulation also decrease the carbohydrate supply to the roots. Thus, Fred and Wilson (5) and Orcutt and Wilson (11) have shown that at nitrate concentrations sufficient to decrease the number and size of nodules there occurs a decrease in concentration of soluble sugars in the plant sap. Georgi (7), as well as Fred and Wilson, has shown also that this decrease in nodulation is partially overcome by supplying additional carbon dioxide to the leaves, a treatment that increases the sugar concentration in the tops and roots. The results of Hopkins (8) show in a general way that a high level of soluble nitrogen commonly causes a lower sugar concentration and reduced nodulation. Data in two of these papers show clearly the pronounced sugar concentration gradient, decreasing from the top to the root, to which we made previous reference (2, 3).

Other recent work gives definite, though indirect, evidence of the importance of carbohydrate supply in the phenomenon under discussion. Thornton and Nicol (14) have observed that with increasing nitrate both nodule numbers and volume of bacterial tissue per unit mass of root fall off rapidly. In experiments by Thornton (13), nitrate did not inhibit the production of the root-curling substance by the bacteria but did interfere with its action, except where sugar was added. He states that "these results support the view that the effect of nitrate is casually connected with a reduction in the carbohydrate available to the plant roots or at any rate with the ratio of these carbohydrates to nitrate". Thornton and Rudorf (15) have observed a thickening and suberization of the lateral endodermis of the nodule, similar to wound isolation, following nitrate applications. Changes in the nodule tissue and the prevalence of coccus forms, suggestive of starvation, also occurred.

In spite of these evidences of starvation, Thornton and Rudorf (15) decided tentatively that the nodules suffered from a misuse rather than from a lack of carbohydrate, since the formation of cell wall thickenings indicated to them the presence of carbohydrate in not inconsiderable quantities We believe, nevertheless, that the starvation explanation is to be regarded as the more plausible one and that the observations of these workers, together with others of Thornton (13), merely show in some detail the mechanism of the response of the host plant and bacteria to the decrease in carbohydrate Justification for this interpretation may be had from still other work by Thornton (12) in which he observed that the morphological appearance of carbohydrate-starved nodules on plants placed in the dark did not differ greatly from that of nodules grown with abundant fixed nitrogen. In the dark the cell wall thickenings were not observed, but their formation was hardly to be expected since obviously carbohydrate starvation induced by darkness is attained much more rapidly, and is more extreme than if produced by additions of fixed nitrogen. Most published results (14), in fact, do not show absolute absence of nodule growth even at rather high concentrations of fixed nitrogen; and if the carbohydrate is adequate for some nodule growth, it must be adequate for the formation of wall thickenings, whatever may be the stimulus leading to their formation. Hence, the presence of a certain amount of carbohydrate in nodules on plants supplied abundant combined nitrogen is really not surprising but is to be expected.

Georgi (7) observed that the addition of combined nitrogen caused a definite decrease in the concentration of sugar in the plant sap but a relatively greater decrease in the development of nodule tissue. His data and conclusions are considered in some detail in the section that follows.

NODULE FORMATION AND SUGAR CONCENTRATION

Georgi (7) and a few other workers who have recently considered the subject appear to have supposed that the carbohydrate supply hypothesis implies that a linear relation should exist between sugar concentration in the root sap and nodules produced, although we tried (2, pages 124 to 127; 3, page 437) to guard against the possibility of such an interpretation. We emphasized that wide variations in the growth of plants over extended periods of time are *not* accompanied by correspondingly wide variations in the concentration of soluble sugars in the plant sap. The sugar concentration in inoculated legumes (or non-legumes) is ordinarily neither exceedingly low nor exceedingly high. If carbohydrate production falls off, plant activities are curtailed and the available supply is used largely for respiration. If, on the other hand, carbohydrate synthesis is accelerated, protein synthesis and plant growth are also accelerated, so that during a considerable growth period carbohydrate concentration does not change nearly as much as the dry weights of plants and of nodules. Hence, in the presence of added fixed nitrogen, it is not to be expected that a large decrease in nodulation will be accompanied by a correspondingly large decrease in sugar concentration.

The carbohydrate supply hypothesis says that over a given growth period during which conditions are about normal the amount of nodule tissue produced will be roughly proportional to the amount of carbohydrate delivered to the site of the nodules. It says nothing directly about the effect on nodule production of concentration of carbohydrate in the root sap but does imply, of course, that an orderly relationship between them exists. This relationship depends on the effect which concentration has on the rate of transport of carbohydrate to the nodules. What this effect is, except qualitatively, is apparently unknown. It appears to us, therefore, that Georgi's data are insufficient for testing the carbohydrate supply hypothesis since it is impossible to determine quantitatively from concentration data the amount of nodule tissue to expect on the basis of the hypothesis.

However, if it be assumed that the rate of transport of carbohydrate is directly proportional to its concentration in the root sap, and it is possible that transport may be an increasing rather than a linear function of concentration, it can be shown mathematically that on the basis of the carbohydrate supply hypothesis nodule production will increase approximately exponentially with increase in carbohydrate concentration. In other words, if the sugar concentration is increased two-fold and maintained at this higher level, the *rate* of plant growth and nodule production will also be increased only about two-fold, but the increases in *total dry weights* of both the plant and nodules will be increased several-fold after a considerable growth

period. There are, of course, a large number of reasons well known to students of plant physiology why a close correspondence of observed values with calculated ones might not occur, but the conditions which would lead to so great a departure as to produce a linear instead of an exponential relation would be very much unexpected. Hence, while the relation might not be strictly exponential, it could hardly be other than some kind of increasing one under usual conditions. In spite of the fact that we do not consider Georgi's data pertinent as a test of the carbohydrate supply hypothesis, we calculated, on the assumptions mentioned above, the number of nodules to be expected on some of his high carbohydrate plants. The numbers obtained by calculation were greater than the numbers observed rather than less, as he concluded. If nodule weights had been given rather than numbers, it is likely that the agreement would have been better, since nodule weight usually increases more rapidly than nodule numbers.

We may conclude, therefore, that it follows from the carbohydrate supply hypothesis that any factor which increases the sugar concentration level in the plant and maintains it at this new level during a considerable growth period, should produce a much greater effect on the weight of nodules formed during the period.

EFFECT OF FIXED NITROGEN ON RELATIVE GROWTH OF PLANT PARTS

In a previous (3) publication we pointed out that applications of fixed nitrogen that are sufficient to cause a marked reduction in nodulation also cause a markedly increased growth of the tops and a relatively smaller growth of the roots. We attributed the decreases in the growth of both the nodules and the roots to the same cause, namely, lack of carbohydrate. Wilson (18, pages 23 to 29) apparently misunderstood our views and as a result criticized our paper at some length. His understanding appears to have been that we advanced a theory that a high top-root ratio (abundant top growth at the expense of root development) is the cause of reduced nodulation on legumes given abundant fixed nitrogen. However, while we discussed top-root ratios at some length, we did so only as evidence that fixed nitrogen decreases the carbohydrate supply to the roots by increasing carbohydrate utilization in the tops. We concluded that "decreased nodulation in the presence of soluble nitrogenous salts is due to inadequate carbohydrate supply in the roots". Our position has always been in harmony with his concluding statement that "it appears more probable that the two phenomena" (increased top-root ratio and decreased nodulation) "are connected through a common cause— than that they stand in a cause and effect relation". A detailed consideration of his criticisms would appear to be unnecessary.

In view of Wilson's misunderstanding it seems desirable, however, to restate in part our position regarding top-root ratio in the hope that certain points will be made clearer. We have never stated, nor meant to imply, that any and every condition that causes a wide top-root ratio will cause a relatively small growth of nodules. We con-

sidered *only* the situation where the wide ratio results from the poor growth of roots relative to tops due to deficient root carbohydrate. We have repeatedly stressed the marked difference in carbohydrate supply to the roots and nodules where the plant relies largely or wholly on atmospheric nitrogen in contrast to the conditions where nitrogenous fertilizers are added in abundance. *When fixed nitrogen is not supplied,* the carbohydrate supply to the roots is average or slightly above average, and the total dry weight of the plant, dry weight of nodules, and nitrogen fixed are ordinarily in rough proportion to carbohydrate synthesis. Under these conditions of adequate root carbohydrate, nodules do not necessarily occur proportionally to roots or inversely to top-root ratio when some special factor radically affects nodulation, root growth, or top-root ratio. We consider Wilson in error in assuming that we implied otherwise. *When fixed nitrogen is supplied,* which is the only condition considered by us (3), the situation is very different; root carbohydrate is limited and both nodule and root growth as compared with top growth are depressed somewhat similarly, and for the same reason. While the carbohydrate supply hypothesis attributes this last-named effect to the lowered carbohydrate level, it does not exclude the operation of other influences on top-root ratio or on nodule growth, such as temperature, soil acidity, moisture, aeration, mineral supply, and photoperiodism, especially when the factor is varied to a marked degree.

Thornton (13) and Thornton and Nicol (14) consider that the occasional failure of nodule growth to parallel root growth is a serious objection to the views which we expressed. This does not follow, however, because, as pointed out previously (2, pages 124 to 127; 3, page 437), nodule development is more sensitive to low carbohydrate supply than is root growth, as might be expected. Sometimes, under conditions of low carbohydrate, considerable root growth may occur with little or even no nodule formation, provided, of course, that enough combined nitrogen is present or being fixed to permit the root growth. This occurs often with plants grown in the greenhouse in the winter.

THE NITROGEN HUNGER CONDITION

When the initiation of nitrogen fixation is delayed in young seedlings that are photosynthesizing rapidly and are not supplied with combined nitrogen, carbohydrate accumulates in excess and the plants undergo a nitrogen hunger condition. Reference was made to this special case previously (2). This condition manifests itself after the nitrogen reserves of the seed are exhausted and *before* the nitrogen-fixing process starts functioning. When fixation starts, the rate is frequently extremely rapid until the accumulated excess carbohydrate has been reduced to normal.

This hunger condition is usually overcome after about one week, or occasionally longer, without special treatment, and in spite of the ever-increasing accumulation of carbohydrate and ever-widening carbohydrate-nitrogen ratio up to, if not a little beyond, the time of the initiation of the nitrogen fixation process. This is well illustrated

by the data of Ruffer which have been plotted by Wilson (18, page 21). In experiment 1 of Ruffer's data the total carbohydrate-total nitrogen ratio was about 5:1 when the hunger period started, about 17:1 when nitrogen fixation started, and rapidly decreased after reaching a value of 19:1.

Normal symbiosis may sometimes be hastened by the addition of a little combined nitrogen or by shading for a few days. Orcutt and Fred (10) and Fred, Wilson, and Wyss (6) have recently supplied additional data on this point. Orcutt and Fred (10) conclude that "an extremely high carbon-nitrogen ratio in the plant inhibits nitrogen fixation". Fred, Wilson, and Wyss (6) and Wilson (18) arrive at essentially the same conclusion although stated less definitely. However, we can see no clear evidence that the hunger condition is caused specifically by a wide carbohydrate-nitrogen ratio or "relation", although obviously a high ratio accompanies it. High carbohydrate and low nitrogen also accompany it, and its cause might be either of these three things. And, again, the cause may well be neither. On the basis of our present information, particularly with regard to the effect of added fixed nitrogen in bringing it to a close, it seems to us that of the three possibilities mentioned it is more likely that the hunger condition is due directly to lack of sufficient nitrogen for the building up of normal nodule tissue, for adequate enzyme production, and for the proper functioning of the cells in which nitrogen fixation can occur, than to either excess carbohydrate or high carbohydrate-nitrogen ratio.

On the basis of present information and in agreement with our previous views it appears, therefore, that the existence of a nitrogen hunger condition has little bearing on the carbohydrate hypothesis and certainly no more than on the carbohydrate-nitrogen relation hypothesis discussed below. The carbohydrate hypothesis, as we have repeatedly stated, obviously cannot account for every variation in nodulation and nitrogen fixation that occurs in legumes, but applies only under reasonably normal conditions. When some factor other than carbohydrate, such as very inadequate calcium or phosphorus, poor bacterial strains, or even lack of initial nitrogen, prevents normal growth and fixation under good photosynthetic conditions, carbohydrate must accumulate and temporarily, at least, become a secondary factor in legume symbiosis. This appears to be what happens in the nitrogen hunger condition.

THE CARBOHYDRATE-NITROGEN RELATION HYPOTHESIS

Wilson, who originally (5) favored a carbohydrate supply hypothesis similar to or identical with ours, later (17) decided that it was too limited in its implications and presented a carbohydrate-nitrogen relation hypothesis as a substitute. He (18) presented evidence which indicated to him that "a given carbohydrate-nitrogen balance in the plant will condition a more or less specific response in—number, size, and distribution of the nodules; quantity of nitrogen fixed; onset and duration of the nitrogen hunger stage; and response to light, fixed nitrogen, and other environmental conditions." He defined (18,

page 4) carbohydrate-nitrogen relation or balance, in varying ways involving ratios between soluble or total carbohydrate and soluble or total nitrogen. He set down no very specific rules for judging just which relation is the governing one under any given condition. In part because of this indefiniteness, or failure to be more specific, the hypothesis seems to us to be somewhat intangible and involved. In support of his ideas regarding the importance of the carbohydrate-nitrogen relation Wilson (18) cited data from numerous experiments; but these do not show either that the carbohydrate-nitrogen relation is, or that the carbohydrate supply is not, the factor governing nodulation. Indeed, they can be used to show the importance of carbohydrate supply equally or more reasonably than to show the importance of the "relation".

The relation or ratio may be, and very likely is, merely a resultant and without governing or causative significance. Certainly definite correlations can exist in the complete absence of any causative or regulating relation. By way of illustration let us consider the case of legumes grown under ideal growth conditions except for an inadequate supply of phosphorus. Now, with increasing additions of phosphorus, there will occur increased plant growth, nodulation, and nitrogen fixation. Accompanying these increases there will undoubtedly be a narrowing of the carbohydrate-phosphorus and probably also of the nitrogen-phosphorus ratio The increased plant growth, nodulation, and nitrogen fixation would be correlated with these decreased ratios, but the significance of the correlations would be negligible since it is obvious that under the conditions mentioned the controlling factor is phosphorus alone. Correlation does not, therefore, prove significance or causality, particularly where the correlation is with a relation or ratio rather than with a single varying factor. This idea has been frequently stressed by many writers. For instance, Went and Thimann (16, page 9), in discussing plant hormones, state that while "experiments show that there is a parallelism between a given carbon-nitrogen ratio and a given type of growth, no causal relation has been shown to exist". In the present instance atmospheric nitrogen cannot be fixed by legumes until adequate carbohydrate is present. The correlation appears to us, therefore, to be more reasonably explainable on the basis that nodulation and carbohydrate-nitrogen relation are both dependent on carbohydrate supply, which is the independent controlling factor. Until new experimental results are presented which show that there is no adequate, reasonably direct relation between carbohydrate supply and nodulation in legumes growing under normal conditions and fixing nitrogen, there is clearly no need for a substitute for the carbohydrate supply hypothesis.

As mentioned above, Wilson rejected the carbohydrate hypothesis because he considered it too limited in its implications. Most of these supposed limitations have been discussed above and shown not to exist. But even if we should assume some of them to be real it is difficult to see wherein his hypothesis is any less limited in its implications. According to Wilson's hypothesis, nodulation, etc., increase as the carbohydrate-nitrogen relation widens so long as it does not become too wide. Above this critical point a further widening produces a

reversal or harmful effect (18, page 12). This reversal of the effect, together with the fact that there is no very strong evidence that the carbohydrate-nitrogen relation in itself ever governs or controls nodulation, seems to us to indicate that the hypothesis rests upon a decidedly insecure basis. On the other hand, according to the carbohydrate supply hypothesis, nodulation, etc., normally increase indefinitely with increase in carbohydrate supply. However, if some other factor essential for growth or nitrogen fixation (or both) becomes very limiting and prevents or greatly retards these processes, the carbohydrate may, of course, accumulate if photosynthesis is active. Although the carbohydrate supply is normally the limiting and hence the controlling factor in nodulation, it is not always so, as we have repeatedly stated. It would be surprising, indeed, if it were. Furthermore, if it should be proved in the future, that an accumulation of carbohydrate is directly responsible for poor nodule development and limited nitrogen fixation rather than the resultant of it as the evidence now indicates, such a development would merely necessitate a corresponding change in the hypothesis. It would not necessitate any substitution of carbohydrate-nitrogen relation for carbohydrate supply. Such a modification would only put our hypothesis on a basis comparable with that of Wilson's since he now says that nodulation increases as the relation widens so long as it does not become too wide. We are unable to see, therefore, that the carbohydrate-nitrogen relation hypothesis is any less limited in its implications than the simpler carbohydrate supply hypothesis which he wishes to displace.

In this connection it is interesting to note that Nightingale (9, pages 154 to 155), as part of a long review, has recently expressed the opinion that the cause of the various responses of plants to the carbon-nitrogen ratio, recorded many times in recent literature, is usually either carbohydrate lack or nitrogen lack, depending upon which is in minimum. It would seem that this statement applies to the case under discussion. Where active nitrogen fixation is proceeding, either by free-living or symbiotic organisms, it should be remembered that carbohydrate is necessarily in minimum since the supply of atmospheric nitrogen is in this case available and inexhaustible. Hence growth is roughly proportional to carbohydrate supply. This proportionality, so obvious in the case of a one-celled organism such as Azotobacter, is less obvious in the case of legumes only because the system is so much more complicated. Of course where nitrogen fixation for some reason cannot occur, carbohydrate may accumulate and is not the controlling factor. Our insistence on the preponderating importance of carbohydrate supply under usual conditions does not mean that we think no other independent influences are at work, but rather that such influences are usually relatively unimportant.

Finally, then, it seems to us that the data published since the appearance of our former papers are remarkably consistent in indicating the correctness of the hypothesis which we set forth and that criticisms of it have had their origin in a misapprehension of the hypothesis itself or of its implications.

SUMMARY

Consideration of recently published data and interpretations bearing on carbohydrate supply as applied to legume symbiosis seems to justify the following conclusions:

1. Although there are many special factors which independently influence nodule behavior, the amount or supply of available carbohydrate reaching the roots is normally the chief influence that affects nodulation under variations in photosynthesis and in the presence of either free nitrogen or varying quantities of combined nitrogen. Where nitrogen assimilation is not occurring, as in the nitrogen hunger condition, nitrogen is present in minimum and carbohydrate is not the controlling factor.
2. The inhibiting effect on nodulation of large additions of fixed nitrogen is due chiefly to the resultant lowering of the available carbohydrate supply. Root growth relative to top growth is also lowered for the same reason.
3. A small change in sugar concentration in the root sap may produce a change in mass of nodules several times as large during a considerable growth period because the weight of nodules, like the total dry weight of the plant, tends to increase exponentially.
4. The carbohydrate supply hypothesis accounts for varying degrees of nodulation under different growth conditions more simply, directly, and adequately than the subsequently proposed carbohydrate-nitrogen relation hypothesis.

LITERATURE CITED

1. ALLISON, FRANKLIN E. Importance of carbohydrate supply in legume symbiosis. Nature, 134:144. 1934.
2. ———. Carbohydrate supply as a primary factor in legume symbiosis. Soil Science, 39:123-143. 1935.
3. ———, and LUDWIG, C. A. The cause of decreased nodule formation on legumes supplied with abundant combined nitrogen. Soil Science, 37:431-443. 1934.
4. BOND, GEORGE. Quantitative observations on the fixation and transfer of nitrogen in the Soya bean, with especial reference to the mechanism of transfer of fixed nitrogen from bacillus to host. Ann. Bot., 50:559-578. 1936.
5. FRED, E. B., and WILSON, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Proc. Nat. Acad. Sci., 20:403-409. 1934.
6. ———, ———, and WYSS, ORVILLE. Light intensity and the nitrogen hunger period in the Manchu soybean. Proc. Nat. Acad. Sci., 24:46-52. 1938.
7. GEORGI, CARL E. Influence of the carbohydrate-nitrogen relation on nodule production by red clover. Jour. Agr. Res., 51:597-612. 1935.
8. HOPKINS, E. W. The effect of long and short day and shading on nodule development and composition of the soybean. Soil Science 39:297-321. 1935.
9. NIGHTINGALE, GORDON T. The nitrogen nutrition of green plants. Bot. Rev., 3:85-174. 1937.
10. ORCUTT, FRED S., and FRED, E. B. Light intensity as an inhibiting factor in the fixation of atmospheric nitrogen by Manchu soybeans. Jour. Amer. Soc. Agron., 27:550-558. 1935.
11. ———, and WILSON, P. W. The effect of nitrate-nitrogen on the carbohydrate metabolism of inoculated soybeans. Soil Science 39:289-296. 1935.
12. THORNTON, H. G. The influence of the host plant in inducing parasitism in lucerne and clover nodules. Proc. Roy. Soc., B 106:110-122. 1930.

13. ———. The action of sodium nitrate upon the infection of lucerne root-hairs by nodule bacteria. Proc. Roy. Soc., B 119:474–492. 1936.
14. ———, and NICOL, HUGH. Reduction of nodule numbers and growth, produced by the addition of sodium nitrate to lucerne in sand culture. Jour. Agr. Sci., 26:173–188. 1936.
15. ———, and RUDORF, J. E. The abnormal structure induced in nodules on lucerne (*Medicago sativa* L.) by the supply of sodium nitrate to the host plant. Proc. Roy. Soc., B 120:240–252. 1936.
16. WENT, F. W., and THIMANN, K. V. Phytohormones. New York: Macmillan Co. 1937.
17. WILSON, P. W. The carbohydrate-nitrogen relationship in symbiotic nitrogen fixation. Jour. Bact., 29:82. 1935.
18. ———. The carbohydrate-nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bul. 129:1–40. 1935.
19. ———, and UMBREIT, W. W. Fixation and transfer of nitrogen in the soybean. Zentbl. Bakt. etc., II. Abt., 96:402–411. 1937.

A RELATIONSHIP BETWEEN POLLINATION AND NODULATION OF THE LEGUMINOSEAE[1]

J. K. WILSON[2]

THE occurrence of root nodules on legumes was recorded nearly 500 years ago, but not until 1858 did Lochmann report that nodules do not form on all legumes. Since that date several non-nodulating legumes have been found by various investigators. Only a few of the many species of legumes have been carefully examined in this regard and it should be expected therefore that others will be added to the list.

While studying the leguminous plants and their associated organisms, it was observed that certain species appeared to symbiose as measured by nodulation with strains of the rhizobia whose morphological and physiological characters were almost identical, while other species appeared to symbiose with a large number of diverse strains whose morphological and physiological characters were extremely dissimilar. Thus, there appear to be recognizable at least three divisions of the legumes as related to nodulation, namely, the non-nodulating legumes, those that symbiose with strains nearly alike, and those that symbiose with dissimilar strains of the organism. These divisions appear to merge from one into the other so gradually that sharp demarkations are difficult to make.

All the previous research on the nodulation of legumes includes species of about 40 genera, of which there are about 500, and of only a few of the comparatively large number of strains of the rhizobia. Thus, a more complete list of the symbionts as regards their relationship to each other is needed. From the information available it appears that at one extreme the non-nodulating plants are found and at the other those legumes that nodulate with a large number of strains of the rhizobia, and that an uneven gradation of species from one condition to the other is found between these extremes.

Attempts have been made to explain why plants symbiose with one strain and not with another or not at all with any strain. Apparently no satisfactory explanation exists. The root nodule organisms were divided by Mazé (7)[3] into two groups. One group symbiosed with plants that grew on alkaline soil and the other with plants that grew on acid soil. The limiting hydrogen-ion concentration for the growth of the organisms was roughly correlated by Fred and Davenport (3) with the acidity of the juice expressed from the corresponding plants. A correlation between the protein constitution of the seeds and the specific *Rhizobium* with which the species will symbiose was offered by Baldwin, Fred, and Hastings (1), while Süchting (12) held that the bacteria produce a "toxin" which stimulates the plant to produce an antibody, and that the relationship between these two

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 8, 1938.

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[3]Figures in parentheses refer to "Literature Cited", p. 169.

substances determines whether symbiosis occurs. McDougall (8) suggested that the unusually thick-walled and lignified root hairs of certain non-nodulating plants prevent the symbiosis.

When plantlets are produced from sterile seed and grown in closed containers to the exclusion of all but one strain of the rhizobia, perhaps 1, 10, 50, or 100% of the plants will bear nodules. Such plants as do bear nodules may be several times as large as, and possess a greener color than, those that do not bear nodules. Since all plants grew under the same conditions of nutrition, light, moisture, and temperature, and were exposed to just one strain of *Rhizobium*, it is suggested that those plants which did bear nodules were in some way inherently different from those that did not bear nodules. If this were true, the factors that make them different might appear through a mixing of characters by cross-fertilization. When plants are self-pollinated for a few generations they tend to become homozygous and are considered to be heterozygous only when cross-pollination occurs, although it is possible to have a heterozygous plant that will self. In numerous cases selfing or crossing will occur depending on the source of the pollen that effects fertilization. Thus the extent of cross-pollination or of selfing should influence in the offspring the number of factors permitting nodulation. An effort is made in this paper, therefore, to point out a relationship that may exist between the extent of selfing or crossing and the non-occurrence or occurrence of nodules on legumes.

STRAINS OF RHIZOBIUM EMPLOYED

In this work an effort was made to obtain one or more strains representing most of the plant bacteria group proposed by previous workers. These strains were isolated from the following legumes: *Albizzia julibrissin*, *Amorpha fruticosa*, *Amphicarpa monoica*, *Apios tuberosa*, *Baptisia australis*, *Caragana frutescens*, *Cassia chamaecrista*, *Cicer arietenum*,[4] *Crotalaria spectabilis*, *Dalea alopecuroides*, *Desmodium canadensis*, *Glycene max*, *Laburnum vulgare*, *Lens esculenta*, *Lespedeza striata*, *Lotus corniculatus*, *Lupinus perennis*, *Medicago sativa*, *Onobrychis viciaefolia*, *Oxytropus lambertii*, *Phaseolus vulgaris*, *Robinia pseudo-acacia*, *Sesbania macrocarpa*, *Spartium scoparium*, *Stizolobium deeringianum*, *Strophostyles helvolus*, *Swainsonia coronillafolia*, *Thermopsis caroliniana*, *Trifolium pratense*, *Vicia villosa*, *Vicia villosa* var. Gore, *Vigna sinensis*, and *Wistaria chinensis*.

PRESENTATION OF DATA

In Table 1 the relationship between pollination and nodulation by many strains of the rhizobia is indicated. The species of legumes at the beginning of the list in bracket 0, which are indicated as being completely self-pollinating, do not symbiose as measured by the occurrence of nodules with any known strain of *Rhizobium*. As the list is extended the species symbiose with one or more of the strains, until at the end, where cross-pollination is obligatory, they symbiose with 30 of the 32 strains. For instance those species opposite 0 in the

[4]Used only on *Cicer*.

table apparently symbiose with no known strain of *Rhizobium* with one or two possible exceptions. Those opposite bracket 1 were tested and found to symbiose with only one strain, while those species opposite bracket 30 were observed to symbiose with 30 strains.

If plants are self-pollinating, they should produce seed when covered with bags of cheesecloth to keep the insects away. This

TABLE 1.—*Nature of pollination as related to nodulation* *

	Species of legume	Nature of pollination
0	*Cercis canadensis* L	Completely self-pollinating
	Cercis siliquastrum (L) Koch	
	Gymnocladus dioica (L) Koch	
	Gleditsia triacanthos L	
	Cladrastis lutea (Michx f) Koch	
	Rynchosia phaseoloides	
	Parkinsonia aculeata L	
	Bauhinia purpurea L	
	Ceratonia siliqua L	
	Acacia baileyana F Muell †	
	Cassia 11 sp †	
1	*Cicer arietenum* L	Progressing from self pollination toward cross pollination ↓
	Ulex europaeus L	
	Dorycnium herbaceum Vill	
	Ornithopus sativus Bort	
	Pueraria phaseoloides Benth	
	Psoralea onobrychis Nutt ‡	
	Hippocrepis sp	
2	*Lotus tetragonolobus* L	
	Wistaria frutescens Rafin	
	Indigofera langebergensis L Bolus	
	Stizolobium deeringianum Bort	
	Phaseolus aconitifolius Jacq	
	Phaseolus angularis W F Wight	
	Lupinus perennis L	
3	*Clitoria ternabea* L	
	Laburnum anagyroides Medic	
	Pithecolobium dulce Benth	
	Albizzia lebbeck Benth	
	Crotalaria verrucosa L	
	Thermopsis fabacea DC	
	Baptisia tinctoria R Br	
	Laburnum vulgaris Gris	
	Clitoria sp.	
	Caragana frutescens DC	
	Coronilla glauca L	
	Vicia cracca L	
	Vicia pratense	
	Lathyris pictensis	
	Trifolium pannonicum Jacq	
	Canavalia ensiformis DC	
	Ononis columnae All	
	Platylobium obtusangulum Hook	

*Figures at the left of the brackets indicate the number of strains of *Rhizobium* out of 32 which have been observed to symbiose with the species of legumes to the right of the bracket.
†Partly taken from the literature.
‡*Psoralea* in brackets 1 and 8 represent two lots of seed.

TABLE 1 —*Continued*

	Species of legume	Nature of pollination
4	*Ononis columnae* All	Progressing from self pollination toward cross pollination ↓
	Centrosema pubescens Benth	
	Mimosa invisa Mart	
	Tephrosia noctiflora Boj	
	Bolusanthus speciosus Harms	
	Daubentonia drummondii Rydb	
	Crotalaria anagyroides H B K	
	Lonchocarpa discolor Huber	
	Bolusanthus speciosus Harms	
	Virgilia capensis Lam	
	Tephrosia vogelii Hook	
	Vicia faba L	
	Vicia floridana S Wats	
	Lathyrus odoratus L	
	Dichrostachys nutans Benth	
	Pisum sativum L	
5	*Trifolium dubium* Sibth	
	Psoralea acaulis Stev	
	Caragana pekensis Kom	
	Coronilla varia L	
	Trifolium incarnatum L	
	Lespedeza violaceae Maxim	
	Strophostyles helvolus Torr et Gray	
	Desmodium grandiflora (Walt) DC	
6	*Astragalus falcata* Lam	
	Crotalaria retusa L	
	Vicia villosa Roth var gore	
	Amphicarpa monoica (L) Ell	
	Indigofera sp	
	Phaseolus aureus Roxb	
	Phaseolus lunatus (L)	
	Indigofera Sp	
	Sutherlandia frutescens R Br	
	Desmanthus illinoensis (Michx) MacM	
7	*Mimosa pudica* L	
	Ononis arvensis Linn	
	Trifolium repens L	
	Astragalus brachycarpus Bieb	
	Astragalus mongolicus Bunge	
	Lespedeza fruticosa (L) Britton	
	Vicia villosa Roth	
	Cyamopsis tetragonoloba (L) Taub	
8	*Genista tinctoria* L	
	Crotalaria mysorensis Roth	
	Trifolium alexandrianum L	
	Petalestemon villosum Nutt	
	Tephrosia virginiana (L) Pers	
	Trifolium fragiferum L	
	Cyamopsis tetragonoloba (L) Taub	
	Lespedeza hirta (L) Hornem	
	Vicia pannonicum Jacq	
	Amphicarpa pitcherii T & G	
	Psoralea onobrichis Bort	

TABLE 1 —*Continued*

	Species of legume	Nature of pollination
9	*Leucanea glauca* Benth	
	Crotalaria spectabilis Roth	Progressing from self-pollination toward cross pollination ↓
	Laburnum alpinum Gris	
	Swainsonia coronillafolia Salisb	
	Coronilla linnearus	
	Lespedeza striata Hook et Arn	
	Glycine max (L) Merr	
	Albizzia falcata Backer	
	Baptisia australis R Br	
	Spartium scoparium L	
	Indigofera tinctoria L	
	Petalostemon purpurea (Vent) Rydb	
10	*Colutea cilicica* Bois & Bal	
	Sutherlandia sp	
	Lourea vespertilionis Desv	
	Trifolium suaveolens Willd	
	Astragalus hornii A Gray	
	Melilotus officinalis (L) Lam	
11	*Melilotus alba* Desr	
	Crotalaria striata DC	
	Trifolium agrarium L	
	Psoralea esculenta Pursh	
	Parosella aurea Macbride	
	Galega officinalis L	
	Donia dampieri	
	Astragalus alpinus L	
	Vigna sinensis (L) Endl	
12	*Tephrosia grandiflora* Pers Syn	
	Genista supranubia Spach	
	Crotalaria usaramoensis Baker	
	Trigonella caerulea Ser	
	Robinia kelseyii Hort	
	Prosopis juliflora DC	
	Lespedeza formosa	
13	*Albizzia julibrissin* Biov (Durazzini)	
	Acacia confusa Merril	
	Spartium junceum L.	
	Medicago lupulina L	
	Trifolium hybridum L.	
	Desmodium polycarpum DC	
14	*Anthyllis vulneraria* DC. (L)	
	Indigofera viscosa Lam.	
	Crotalaria incana L	
	Dalea alopecuroides Willd	
	Wistaria chinensis Nutt.	
	Robinia viscosum Vent	
	Erythrina rubrinervia H B K	
	Cajanus indicus Spreng	

should be a reliable method for detecting self-sterility or self-compatibility, provided the plants are not wind-pollinated. Accordingly, racemes of flowers of *Cladrastis lutea*, a non-nodulating plant, were

TABLE 1.—*Continued.*

	Species of legume	Nature of pollination
15	*Desmanthus leptalobus* T.G. *Crotalaria polysperma* Kotschy *Lotus corniculatus* L. *Astragalus membranaceus* Bunge *Glycyrrhiza lepidota* Nutt. *Vigna affinis*	Progressing from self-pollination toward cross pollination ↓
16	*Trifolium pratense* L.	
17	*Cassia chamaecrista* L. *Trigonella foenum-graecum* L. *Petalostemon oligophylla* *Vigna vexillata* Rydb.	
18	*Crotalaria intermedia* Kotschy. *Crotalaria lanceolata* E. Meg. *Astragalus cicer* Linn. *Oxytropus lambertii* Pursh *Erythrina crista galli* L. *Pueraria hirsuta* Schneid *Dolichos lignosus* DC.	
19	*Vigna retusa* Walp. *Crotalaria alata* *Ononis vaginalus* Vahl.	
20	*Acacia decurrens* Willd. *Crotalaria hildebrantii* Vetka *Ononis vaginalis* Vahl. *Crotalaria juncea* L. *Crotalaria sagittalis* L. *Amorpha microphylla* Pursch. *Colutea arborescens* L. *Indigofera trila* L.	
21	*Piptanthus nepalensis* D. *Crotalaria mundyi* Baker *Onobrychis sativa* Lam	
22	*Galega hartlandii* *Crotalaria maxillaria*	
23	*Desmodium canadensis* (L) DC.	
24	*Crotalaria falcata* Vahl.	
25	*Thermopsis caroliniana* M.A. Curt. *Amorpha elata* Bouche *Astragalus rubyi* *Kennedya monophylla* Vent.	↑
26	*Medicago sativa* L.	**Progressing from obligatory cross-pollination toward self-pollination**
27	*Phaseolus vulgaris* L.	
28	*Amorpha fruticosa* L.	

TABLE 1.—*Concluded.*

	Species of legume	Nature of pollination
29	*Amorpha canencens* (Nutt) Pursh. *Crotalaria grantiana* Harvey *Centrosema virginianum* (L) Benth *Phaseolus coccineus* L.	↑
30	*Chorizema illicifolia* Labill *Robinia pseudo-acacia* L. *Sesbania macrocarpa* Muhl	Progressing from obligatory cross-pollination toward self-pollination

*Figures at the left of the brackets indicate the number of strains of *Rhizobium* out of 32 which have been observed to symbiose with the species of legumes to the right of the bracket

thus protected. After sufficient time it was observed that practically every flower produced a pod. Plants of *Cassia tora*, also a non-nodulating plant, were grown from seed in the greenhouse where the flowers could not be worked by insects. Abundant seed formation was observed. Such data might indicate that all the species in the list of non-nodulating plants in Table 1 are self-pollinators.

Following those species that do not bear nodules come *Cicer arietenum*, *Ulex europaens*, *Dorycnium herbaceum*, and *Ornithopus sativus*, species that have been observed to symbiose with only one of the strains employed. The strain that symbiosed with *Cicer* was obtained from the Soviet Republic and was isolated from *Cicer* by S. G. Rasunowskaje of the University of Leningrad[5] The strain that symbiosed with *Ulex* was isolated from *Stizolobium deeringianum* and was obtained from the U. S. Dept. of Agriculture. The strain that symbiosed with *Ornithopus* was isolated from *Lens esculenta* and the one that symbiosed with *Dorycnium* was isolated from *Caragana frutescens*.[6] The seven species in bracket 1 are probably all self-pollinating or nearly so. Howard, *et al.* (5) state that the anthers of *Cicer* dehisce and pollination occurs in the bud stage, insuring self-fertilization. Data from the literature on the degree of cross-pollination or self-fertilization for the other species and for a majority of the other plants listed in the table were not available. Cheesecloth bags, therefore, were placed around flowers of many species of legumes. By such a procedure it was observed that *Vicia pratensis* produced about as many seed pods in the bags as outside the bags, and it is a common observation of florists that unless the flowers of *Lathyrus odorata* are removed, seed pods will appear without the flowers having been visited by insects. Seed pods were readily produced in cheesecloth bags by *Caragana pekensis*, *Amphicarpa monoica*, *A. pitcherii*, *Trifolium agrarium*, *T. fragiferum*, *Medicago lupulina*, *Melilotus alba*, *Colutea arborescens*, and *Glycine max*. If the work of Garber and Odland (4) is consulted, it is evident that natural crossing with soybeans (Glycine) may vary more than 100% from one year to another, although the number of such natural crosses is rather small. Wood-

[5]Personal communication, 1935.

[6]A complete record of strains that symbiosed with each species can be found in Cornell Univ. Agr. Exp. Sta. Mem. 221. 1939.

worth (15) found only 0.16% natural crossing in this species. Racemes of flowers of *Baptisia australis* were also covered. In one case three pods developed on one raceme. Each pod had only a few seed instead of many as was the case with other pods not covered. The data in Table 1 show that *B. australis* symbiosed with only nine of the strains. Kirk (6) states that *Melilotus alba* sets seed when protected from visitation by insects, while *M officinalis* did not do so under such conditions without artificial manipulation. In the table it can be seen that these last three species will symbiose with about 10 times as many strains of rhizobia as *Cicer* but with about only one-third of the strains employed.

Natural crossing in *Vigna sinensis* was found by Piper (9) to occur rarely in most localities but in some instances natural crossing occurred more frequently. If Table 1 is consulted, it can be seen that *Vigna* symbiosed with 11 of the strains. Fergus (2) reached the conclusion from artifically fertilizing heads of red clover that some lines were highly self-fertile and Williams (14) agrees with Fergus that the degree of self-sterility varies with different plants. It would seem, therefore, that red clover cross-pollinates more readily than *Vigna* does, and it is evident from Table 1 that *Trifolium pratense* will symbiose with a larger number of strains of *Rhizobium* than *Vigna*. Crosses may even occur between various species, for Piper, *et. al.* (10) found that pollen of *Medicago falcata* was as efficient in fertilizing *M. sativa* as pollen from other *sativa* plants. This fact was checked by Waldron (13) who planted the two species in equal numbers and grew plants the following year from the seed. The number of hybrids from *Medicago falcata* reached as high as 42.7%. The data presented in this paper show that *Medicago sativa*, a plant that can and may be highly cross-pollinated, will symbiose with 26 of the strains. Such comparisons are cited to emphasize the relationships that might exist between pollination and symbiosis.

Flowers of certain other species were covered to test the necessity of cross-pollination for seed production. About 800 flowers of *Robinia pseudo-acacia* were thus covered. Only three pods developed. One contained two seeds, the other two one seed each. Also, numerous flowers of *Chorizema illicifolia* developed in a greenhouse during a period of three seasons where they could not be visited by insects. Not a seed was ever observed unless the flowers were artificially manipulated. Similar results were obtained with flowers of *Erythrina crista galli*, except the flowers were never worked. Bags were placed over a large number of the flower racemes of *Amorpha fruticosa*. Although no counts were made, it was evident that the setting of seed was favored by the degree of visitation of insects. From the table it can be seen that plants as thoroughly dependent on cross-pollination as *Robinia*, *Chorizema*, *Amorpha*, and certain other legumes, will symbiose with about 30 times as many strains of the rhizobia as will *Cicer*, a self-pollinating plant.

The suggestion can be made after observing the data in Table 1 that as self-pollination becomes less frequent, the number of species of plants symbiosing with a larger number of strains increases. This tendency exists about one-half way through the list of 184 species.

As the end of the list is approached where cross-pollination is more and more obligatory, the number of species symbiosing with a constantly increasing number of strains drastically decreases.

In adaptation studies of strains of *Rhizobium* to other species of plants, the adaptation can be effected more easily if the strain is offered the opportunity to symbiose with a plant that carries about the same degree of cross-pollination as that from which the strain was isolated. If a strain is isolated from a species that is largely self-pollinating, such as *Vigna sinensis* or *Albizzia julibrissin*, it may be adapted to a large number of species of legumes, but if it is isolated from a species that is highly cross-pollinating, such as *Amorpha fruticosa*, *Phaseolus coccineus*, or *Chorizema ilicifolia*, it may not be easily adapted to the self-pollinating plants. Much will depend, however, on the particular strain that is being employed in the test. Such a condition indicates that a strain isolated from a group of homozygous plants may also symbiose with a group of plants that is heterozygous. The reverse, however, may not be true because the strain of Rhizobium may be radically different. Such non-reciprocal relations have been described by Sears and Clark (1930).

Studies concerning the relationship between the morphology of the strains of the rhizobia and the nature of pollination should be mentioned. If in the whole group of rhizobia certain strains are considered as being predominantly monotrichic and others as predominantly multitrichic with all gradations of flagellation between, then a relationship between self- and cross-pollinating plants and the strain of *Rhizobium* with which they will symbiose becomes evident. Those strains that are predominantly monotrichic will, almost to the exclusion of all other strains, symbiose with plants that are self-pollinating or largely so, while those strains that are predominantly multitrichic will more often symbiose with species that are more freely cross-pollinating. In many instances, however, the predominantly monotrichic strains may be observed symbiosing with cross-pollinating plants. Thus, the predominantly monotrichic strain commonly encountered symbiosing with *Vigna sinensis*, a plant highly self-pollinating, will symbiose with *Amorpha fruticosa*, a plant highly cross-pollinating.

Since the degree of cross-pollination may be an index to the number of strains that will symbiose with a species, it may explain why various species of a genus appear scattered throughout the list in the Table 1. As an illustration, *Crotalaria verrucosa* appears in bracket 3, while *C. grantiana* appears in bracket 29. Seventeen other species appear between these extremes. It would be suspected, therefore, that *C. verrucosa* is highly self-pollinating, while *C. grantiana* is highly cross-pollinating, although data substantiating the suggestion are not available. Similar conditions exist with species of *Trifolium* and also with other species.

If the degree of selfing or crossing will influence the ratio of the species of a genus that will symbiose with certain strains of rhizobia, it might be possible to detect similar differences in various lots of seed from the same species. Thus, seeds of *Medicago sativa*, a plant that under certain conditions may be considerably self-fertilized and

under other conditions largely cross-pollinated, may exhibit such differences if seed containing certain heritable characters are properly tested. In this connection two lots of seed of Medicago were obtained. One was labeled alfalfa, while the other one was a self-tripping Grimm alfalfa. Seeds of these two lots were grown to ascertain their symbiobility with strains of rhizobia.

The results showed that the Grimm alfalfa symbiosed with the strains isolated from *Apios tuberosa*, *Caragana frutescens*, *Desmodium canadensis*, *Lespedeza striata*, *Medicago sativa*, and *Stizolobium deeringianum*. The other alfalfa did not symbiose with any one of the strains employed It is suggested that other tests of this nature should be made before conclusions are drawn.

DISCUSSION

For the past 50 years botanists and agricultural bacteriologists have studied the legumes and their associated organisms During this time about 20 plant-bacteria groups have been proposed. These groups are supposed to represent a rather specific relation between the plant and the particular strain of the bacteria. Unfortunately there are so many exceptions to the proposed groupings that one cannot use them with certainty If a logical explanation could be offered for the exceptions it might lead to a better understanding of the whole situation. The suggestion is made in this report that a relationship exists between the degree of cross-pollination and the number of strains of *Rhizobium* with which a plant will symbiose. It appears that plants which are self-pollinating naturally contain or have developed comparatively pure lines which carry none or only a few characters that make symbiosis possible, or carry them in a recessive condition, while those plants that are cross-pollinating have developed or maintained to a surprising degree those characters in a dominant state which make it possible for the plants to symbiose with a large number of strains of the rhizobia. It seems that many unexplained facts can be accounted for if the symbiotic relation is a genetic one.

Just what percentage of crossing is obligatory to maintain the necessary degree of heterogeneity for symbiosis is not known. The data presented in this paper, therefore, are only relative and the position of certain plants listed in Table 1 may be shifted when further information is obtained. The fact that many data on the number of strains with which the plant will symbiose were obtained under conditions that might not have been altogether suitable for the plant or bacteria may also make necessary a relocation of certain plants. Also, if pollination produces different degrees of heterogeneity, it should be suspected that the particular sample of seed employed in a piece of work could hardly be duplicated at another time. This, however, would not obtain to the same degree with seeds from plants that are known to be homozygous or nearly so. The degree of selfing or crossing that occurs in any particular species in any one year may modify drastically the seeds of that species. This may offer an explanation of the frequently discussed practical question of having a culture for inoculating the crop composed of several strains. One strain might

symbiose adequately with one fraction of the seed and another strain with still another fraction. If the degree of cross-pollination is a factor influencing symbiosis, it should be suspected that a plant at one time would not symbiose with certain strains, while the seedlings from that plant might do so because of the heritable characters combined in the crossing. This means that a strain of *Rhizobium* could appear inefficient at one time and efficient at another. Thus, the plant probably becomes the dominant member in symbiosis because it is the one which can and might change its characters most readily through pollination. Probably one reason why more plants have not become non-nodulating is that a plant's own pollen may be non-compatible, or that only those plants survive which can nodulate. This makes it necessary that many species which survive remain heterozygous and thus maintain those characters that permit promiscuous symbiosis.

Since plant resistance to certain diseases is a genetic factor and may be dominant or recessive, depending upon certain relations, it would be interesting to know whether resistance to the legume bacteria is also a genetic factor and whether segregation for non-nodulation or nodulation would occur on a simple Mendelian 3:1 ratio. It is known, however, that cross-pollination often produces in the offspring increased growth or heterosis and this may account in part for the variation in nodulation.

SUMMARY AND CONCLUSION

Evidence has been presented to show that a relationship may exist between pollination and nodulation of species of legumes Plants that are completely self-pollinating may not bear nodules, or if they do, the number of strains of rhizobia with which they will symbiose will be small. If cross-pollination is obligatory the number of strains with which the plant will symbiose will be comparatively large. The strains of rhizobia symbiosing with self-pollinating plants appear predominantly monotrichic, while those that symbiose with cross-pollinating plants appear predominantly multitrichic, although both morphological types may be found symbiosing with cross-pollinating plants. Such a relationship apparently does not correlate in any way with the order, tribe, genus, or species of the plants, except as it may be influenced by pollination. If this suggested relationship is valid it will place symbiosis on a heritable basis and in the same category as are certain heritable plant diseases.

LITERATURE CITED

1. BALDWIN, I. L., FRED, E. B., and HASTINGS, E. G. Grouping of legumes according to biological reactions of their seed proteins. Bot. Gaz., 83:217–243. 1927.
2. FERGUS, E. N. Self-fertility in red clover. Ky. Agr. Exp. Sta. Circ. 29. 1922.
3. FRED, E. B., and DAVENPORT, A. Influence of reaction on nitrogen-assimilating bacteria. Jour. Agr. Res., 14:317–336. 1918.
4. GARBER, R. J. and ODLAND, T. E. Influence of adjacent rows of soybeans on one another. Jour. Amer. Soc. Agron., 18:605–607. 1926.
5. HOWARD, A., HOWARD, F. L. C., and KHAN, A. R. Some observations of Indian Grain (*Cicer arietinum* L.) Mem. Dept. Agr. India, Bot. Ser., 7:213–235. 1915.

6. KIRK, L. E. Breeding sweet clover and lucerne. Imp. Bureau Plant Gen. Herb. Plants. Bul. 7. 1927.
7. MAZÉ, M. Les microbes des nodosites des Légumineuses. Ann. Inst. Pasteur, 13:145 155. 1899.
8. MCDOUGALL, W. B. Thick-walled root hairs of Gleditsia and related genera. Amer. Jour. Bot., 8:171–175. 1926.
9. PIPER, C. V. Agricultural varieties of the cowpea and immediately related species. U. S. D. A. Bur. Plant Ind. Bul. 229. 1912.
10. ——— ———, EVANS, M. W., MCKEE, B., and MORSE, W. J. Alfalfa seed production, pollination studies. U. S. D. A. Bul. 75. 1914.
11. SEARS, O. H., and CLARK, F. M. Non-reciprocal cross-inoculation of legume nodule bacteria. Soil Science, 30:237-242. 1930.
12. SÜCHTING, H. Kritische studien uber die Knollchenbakterien. Cent. Bakt. (etc.) 2 Abt., 11:377–388; 417–441; 496–520. 1904.
13. WALDRON, L. R. Cross-fertilization in alfalfa. Jour. Amer. Soc. Agron., 11:259–266. 1919.
14. WILLIAMS, R. D. Studies concerning the pollination, fertilization and breeding of red clover. Univ. College Wales. Welsh Plant Breed. Sta. Ser. H No. 4. 1925.
15. WOODWORTH, C. M. The extent of natural cross-pollination in soybeans. Jour. Amer. Soc. Agron., 14:481–495. 1922.

NOTE

A MIXER AND SAMPLER FOR GREENHOUSE SOILS

IN greenhouse pot culture work it is frequently desirable to mix a small quantity of fertilizer with 4 to 10 kilograms of soil. Again it often becomes necessary to analyze the soil in greenhouse pots. It is difficult in such an analysis to obtain a small sample which is a true aliquot of an entire pot of soil. The mixing of 8 to 10 kilograms of soil on an oilcloth with sufficient thoroughness to make possible the removal of a small representative sample is extremely difficult. Accordingly, a mechanical mixer and sampler was constructed and has been used in the soils greenhouse of the Michigan Agricultural Experiment Station for two years. A description of the apparatus follows.

As shown by Fig. 1, the mixer consists of a 15-inch cubical sheet metal box with rounded corners and with a ½-inch steel shaft passing through diagonally opposite corners. A crank on one end of the shaft is used to turn the mixer. The cover, consisting of about three-fourths of one side of the mixer, is on hinges and is fastened by means of screw clamps which slip apart as soon as they are loosened. This arrangement makes it easily opened. A rubber gasket keeps the soil from sifting out during mixing.

As the mixer is turned, the soil rolls from corner to corner six times during each revolution. To hasten the mixing two 3-inch triangular baffle plates were welded into the edges opposite the cover and half way between the corners. As the mixer is turned these plates carry a portion of the soil up and allow it to fall on top of the remainder.

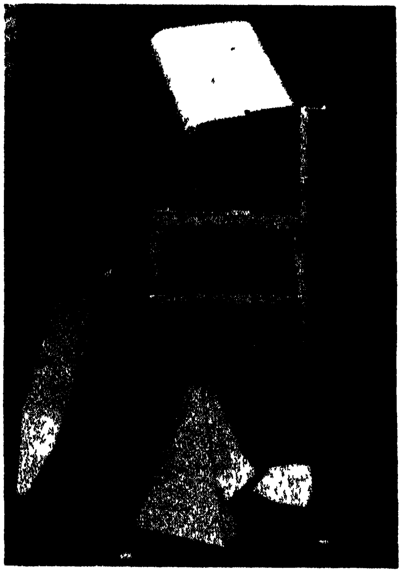

FIG. 1.—A mixer and sampler designed for use in mixing fertilizers with greenhouse soils and in sampling greenhouse pot culture soils for chemical analyses.

The sampler consists essentially of two parts, a square funnel, 16 inches at the top and 3 inches at the bottom, and a pyramid 17 inches high with a 12-inch square base. The funnel is fitted with a slide to hold the soil. The edges of the pyramid are turned out a distance of 1½ inches and one side is fitted with a piece of metal so arranged as to direct soil into a small tray made for that purpose.

In operation the pyramid is placed under the funnel. The height of the 1½-inch angle iron frame is such (38 inches) that the funnel comes down over the top of the pyramid. When the slide is quickly

TABLE 1.—*The results of nitrogen tests made to show the efficiency of the soil mixer and sampler shown in Fig. 1.*

Sample No.*	Percentage of total nitrogen in replicated pots†										
	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Pot 6	Pot 7	Pot 8	Pot 9	Pot 10	Mean
1	0.149	0.150	0.152	0.149	0.151	0.151	0.150	0.151	0.156	0.150	0.1509
2	0.151	0.147	0.152	0.152	0.148	0.153	0.149	0.152	0.155	0.153	0.1512
3	0.149	0.152	0.152	0.151	0.152	0.153	0.149	0.151	0.156	0.151	0.1516
4	0.151	0.153	0.150	0.152	0.152	0.149	0.149	0.150	0.154	0.151	0.1511
Mean	0.1500	0.1505	0.1515	0.1510	0.1508	0.1515	0.1493	0.1510	0.1553	0.1513	0.1512

*One sample was taken for analysis from each quarter of each pot of soil.
†Each pot of 10 kg. of soil was treated with 50 grams of $(NH_4)_2SO_4$.

removed, the soil from the funnel is divided into four almost equal portions. One portion is caught in the small tray and is returned to the funnel for another quartering. Three quarterings will thus reduce a 10,000-gram pot of soil to approximately 150 grams. By returning the soil sample to the funnel in a paper it is possible to eliminate an error caused by the larger particles becoming separated from the finer during the process of pouring it into the funnel.

The large tray, 18 x 30 inches, is placed under the pyramid and smaller tray during operation

To test the thoroughness with which this apparatus will mix a pot of soil, 10 pots were filled with 10 kilograms each of Plainfield sand. To each pot was added 50 grams of $(NH_4)_2SO_4$. The contents of each pot was then mixed by turning it 25 times in the mixer.

The cultures were then wetted and kept at optimum moisture for 18 days, after which the soil in each culture was dried and again mixed by turning 50 times in the mixer. By means of the divider each culture was then quartered and a sample taken from each quarter for analysis. Total nitrogen by the Kjehdahl method was determined on each sample. Based on the mean percentage of nitrogen, the recovery of applied nitrogen was 96.84%. Nitrate nitrogen was not determined.

According to the data presented in Table 1, the variations in the percentage of nitrogen between samples from the same pot were very slight. Considering the means for the 10 pots, this percentage ranged from 0.1509 to 0.1516 To determine the significance of the mean differences the data were analyzed by analysis of variance. As shown by the results of this analysis (Table 2), a between sample variance of 0.00000087 compared to an error variance of .00000235 (F equals 2.701) shows there was not a significant difference between the means of any two samples. This proves that each pot of soil was thoroughly mixed when the samples were taken.

TABLE 2.—*Analysis of variance for nitrogen tests made to show efficiency of soil mixer and sampler shown in Fig. 1.*

Source of variation	Degrees of freedom	Sum of squares	Variance	F	Estimate of S D
Total .	39	.0001564			
Between samples	3	0000026	00000087	2 701	
Between pots . . .	9	0000904	00001004	4.272	
Error. . . .	27	.0000634	00000235		.001533

The results do show, however, that a difference existed between the nitrogen contents of various pots. A variance of 0.00001004 between pots resulted in an F value of 4.272, significant to the 1% point. A test for significance between the means of pots shows that pot 9 contained a significantly higher percentage of nitrogen than did any of the other pots but that no significant difference existed between any of the other means. In other words, when pot 9 was eliminated the analysis of variance for the data from those remaining shows that there was not a significant difference between any of the means. The variance between pot 9 and the other pots may have been caused by several factors. Perhaps an error was made in weighing the ammonium

sulfate or there may have been a difference in the rate of nitrification in that pot as compared to the others. This could have resulted from either a lower or higher moisture content. If the rate of nitrification was lower, the quantity of nitrogen remaining in a form which could be determined by the Kjeldahl method would have been correspondingly higher.

As a result of these data it seems safe to conclude that the apparatus described is capable of thoroughly mixing a 10-kilogram sample of soil.—R.L. COOK, *Soils Section, Michigan State College, East Lansing, Michigan.*

BOOK REVIEW

STATISTICAL TABLES FOR BIOLOGICAL, AGRICULTURAL, AND MEDICAL RESEARCH

By R. A. Fisher and F. Yates. Edinburgh: Oliver and Boyd. VIII+90 pages. 1938. 12/6.

WHILE this attractive volume includes those tables familiar to all readers of Professor Fisher's "Statistical Methods for Research Workers," it contains a notable amount of useful material besides. Of especial interest to the agronomist is the attention devoted to the mechanism of designing experiments in agriculture. One is somewhat startled at first sight of the four large pages of Latin squares, including the complete sets of orthogonal squares 9×9 and smaller. These, supplemented by the six pages of random numbers, are useful in designing various types of complex experiments. Following them are other tables with special solutions of balanced incomplete blocks and a convenient index for picking out the design that meets the requirements of the experimenter. While a liberal amount of explanation is given in the introduction, the reader is not advised to attempt to design and analyze a complex experiment before a careful study of the references listed.

With the rapid development of the applications of polynomial fitting by Fisher, Hopkins, Tippett, Wishart, Kalamkar, Cochran, and others, the investigator in agronomy using this method will welcome the labor-saving devices made available in these tables. Since orthogonal polynomials promise great advances in the examination of weather-crop relations and growth curves, any lightening of the labor of computation is a welcome contribution.

In some plat experiments the investigator is concerned with counts of infested or diseased plants, often expressing the results as percentages. If the distributions are not normal the F-test of significance in analysis of variance may be invalid. Appropriate transformations are discussed in these tables. Emphasis is laid on the probit transformation of Bliss, complete tables being quoted together with a worked-out example. Angle and other transformations are specified.

The tables peculiar to Professor Fisher's developments of statistical methods are supplemented by the customary logarithms, squares, square roots, reciprocals, sines, tangents, etc. Those who deal with ranked data will be interested in a table for transforming these into normally distributed scores. Many people who object to the use of an auxiliary table of natural logarithms for making the z-test will be pleased to find F tabulated under the caption, "Variance Ratio."

The agronomist will find this book of tables a useful addition to his kit of statistical tools. (G. W. S.)

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STUDENT SECTION ESSAY CONTEST FOR 1939

STUDENTS presenting the best papers will receive awards as follows: The first three winners will receive expense money to enable them to attend the International Grain and Hay Show in Chicago. The total allotment for the three will not exceed $150.00. The amounts granted will vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student, as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men will receive appropriate medals and a year's subscription to the Journal of the American Society of Agronomy. The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of $20, $15, $10, and $5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1938-39 school year or those graduating during the summer school of 1939 are eligible, providing their papers are submitted before graduation. A certification of eligibility to qualify as an undergraduate, signed by the Dean of the College, must accompany each paper.

Papers should be typed, double spaced and not over 3500 words in length. *Abstracts of not more than 500 words must accompany each paper*. Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "The Work of Early American Agronomists".

"Early Agronomists" is taken to mean any agronomist no longer living. Not less than one nor more than four men are to be considered in the essay.

All papers are to be submitted in duplicate and if it is desired that the essay be returned, postage should be enclosed.

The committee suggests, that where several papers are entered from a given institution, the local representatives of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expense.

Essays must be in the hands of the Chairman of the Committee on Student Sections, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than August 1, 1939.

NEWS ITEMS

DR. JOHN H. PARKER, Professor in Charge of Crop Improvement, Kansas State College, has resigned after 21 years of service to become Director of the Kansas Wheat Improvement Association. Dr. Parker's address will continue to be Manhattan, Kansas.

LOUIS P. REITZ, U. S. Dept. of Agriculture, has been appointed as Associate Professor in Charge of Crop Improvement, Kansas State College, to succeed Dr. John H. Parker, resigned. Mr. Reitz' appointment took effect February 1, 1939.

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SCARIFICATION STUDIES ON SOUTHERN GRASS SEEDS[1]

GLENN W. BURTON[2]

PASTURE men report that considerable difficulty is experienced in establishing some of the southern grasses with seed. While environmental factors probably play the dominant rôle in the successful establishment of pastures from seed, the poor quality of the seed planted may often explain the failures which result Numerous studies made with the aid of a seed blower[3] indicate that from 50 to 75% of the florets of many southern grasses often fail to form caryopses. The complete separation of empty florets from those containing caryopses with ordinary seed cleaning machinery is difficult, and, hence, seed may appear upon the market which germinates poorly because of the large percentage of empty florets present. Ergot, *Claviceps paspali*, on Dallis grass, *Paspalum dilatatum*, and Bahia grass, *Paspalum notatum* and *Cerebella paspali* on carpet grass, *Axonopus affinis*, attack the caryopses and may be so severe as greatly to reduce the number of seedlings expected from a pound of seed.

Germination studies made in 1936 upon florets containing sound caryopses indicate that delayed germination was often experienced. Ray and Stewart[4] make reference to this condition in *Paspalum dilatatum*, *P. floridanum*, and *P. pubiflorum* and indicate that removal of the lemma and palea or scarification with 37% HCl for 3 to 10 minutes in the case of *P dilatatum* will cause the seed to germinate more readily. Southern weeds and annual grasses grow so rapidly in freshly prepared soil that pasture grass seedlings appearing 3 to 6 weeks after planting usually experience very severe, and often fatal, competition. Any treatment which will hasten the germination and

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, the Georgia Agricultural Experiment Station, and the Georgia Coastal Plain Experiment Station at Tifton, Georgia. Received for publication December 8, 1938.

[2]Agent, U. S. Department of Agriculture, Tifton, Georgia.

[3]BURTON, GLENN W. A useful seed blower for the grass breeder. Jour. Amer. Soc. Agron., 30:446-448. 1938.

[4]RAY, C. B., and STEWART, RALPH T. Germination of seeds from certain species of Paspalum. Jour. Amer. Soc. Agron., 29:548-554. 1937.

early growth of these grasses should give them a better chance to meet this unfavorable competition successfully.

Bahia grass, *Paspalum notatum*, has been one of the most promising pasture plants grown in south Georgia and Florida. The scarcity of viable seed of this species has been the principal factor limiting its use. Seed yields made on some 3,500 seedlings indicate that desirable strains producing 300 to 600 pounds of seed per acre can be found. It is apparent from the following results, however, that the chances of selecting a strain capable of producing seed which will germinate readily are not great.

To determine the ability of different plants to produce seed which will germinate rapidly, 100 seeds (florets containing caryopses) from each of 175 Bahia grass plants were sown in flats of steam-sterilized soil in the greenhouse on September 4, 1937. These were kept moist at temperatures ranging from 75° to 100° F throughout the test. On October 1, from one to two seeds had germinated in 28 of the rows and none of the other 147 samples showed any sign of growth. By October 15 only 76 samples had begun to germinate, and on December 8, more than 3 months after planting, 35 rows had still failed to germinate and the other 140 samples averaged 3.2 seedlings per 100 seed planted. One lot of seed, after 3 months, germinated 22%; the next best sample, 11%.

EXPERIMENTAL

All germination studies described here were made by planting 100 seeds (florets containing caryopses unless otherwise specified) in rows in flats of steam-sterilized soil in the greenhouse. The steam-sterilized soil was rendered free of toxic substances by leaching prior to its use. The soil was kept moist throughout each test. The temperature varied with the season, being somewhat warmer during the summer than in mid-winter. The source of seed used in these studies may be found in the tables.

Most of the seed treatments, listed in the tables and chosen with the thought of increasing the permeability of the seed to water, need no description. The success experienced with the use of dry heat to scarify alfalfa seed made a heat treatment seem desirable. All acid and alkali treatments were made by stirring a small quantity of seed in a beaker of the scarifying medium for the period designated. The seeds were then washed in running water for 5 to 10 minutes and finally spread out to dry.

RESULTS

From Table 1 it is apparent that subjecting Bahia grass seed to 70° C for 4 hours, or soaking them in water with and without reduced pressure, does not increase significantly the rate of germination. Removing the palea and both glumes with sandpaper scarification, however, did hasten germination materially. The variation in response to sandpaper scarification noted in the 1936 and 1937 seed is due to the fact that the 1936 seed, being drier than the 1937 sample, had to be rubbed harder to remove both glumes and more of the caryopses were cracked and apparently killed. Treatment of the 1936 seed with concentrated H_2SO_4 for 5 minutes caused the seed to germinate 32% in 1 week, and 56% 2 weeks after planting as com-

pared with 0 and 9% for untreated seed. Increased germination was also obtained following H_2SO_4 scarification of the 1937 seed. Treatment of Bahia seed for 5 minutes with concentrated HCl had very little effect on the germination rate.

TABLE 1.—*The influence of various seed treatments upon the germination of Bahia grass seed planted in triplicate in steam-sterilized soil in the greenhouse, August 7, 1937.**

Seed treatment	Seed harvested Aug. 31, '36, % germination after			Seed harvested Aug. 3, '37, % germination after		
	6 days	13 days	20 days	6 days	13 days	20 days
No treatment	0	9	24	0	1	1
70° C for 4 hours	0	14	23	0	0	1
Soaked in water 24 hours	2	14	24	0	2	2
Soaked in water 24 hours and suction	0	14	27	0	0	1
Palea removed	12	13	17	6	19	26
Sandpaper scarification†	6	11	11	40	49	52
Conc technical H_2SO_4 for 5 minutes	32	56	57	2	14	16
Conc. HCl for 5 minutes	1	7	11	0	0	5

*The 1936 and 1937 seed tested here was harvested from the same plat of Bahia grass growing at Tifton, Georgia Prior to the test, the seed was stored in a semi-basement room where humidity was slightly above normal

†Seeds were rubbed between sandpaper blocks until the caryopses were freed from the glumes.

The immediate germination of the 1937 seed, following removal of the glumes, indicates that Bahia grass seed unlike many other grasses requires little if any rest period. Other experiments not reported here substantitate this conclusion.

The germination of 9 and 24% obtained on the untreated 1936 seed 2 and 3 weeks after planting is the best germination of untreated Bahia seed recorded in the many tests run at Tifton This test suggests that 1-year-old Bahia grass seed will germinate better than freshly harvested seed In Table 2, however, this same untreated 1936 seed, 3 weeks after planting, germinated only 0.3%. This difference is believed to be due to the variation in greenhouse temperatures. In August when the first test was made, mean temperatures fluctu-

TABLE 2.—*The effect of the time factor in the acid scarification of Bahia grass seed planted in triplicate in steam-sterilized soil in the greenhouse October 1, 1937.**

Length of time seed were stirred in conc. technical H_2SO_4	Seed harvested Aug. 31, '36, % germination after			Seed harvested Aug. 3, '37, % germination after		
	8 days	14 days	21 days	8 days	14 days	21 days
No treatment....	0	0	0.3	0	0	0.3
2½ minutes........	5	13	17	10	24	31
5 minutes........	11	22	26	13	28	34
10 minutes.........	42	60	64	52	56	57
15 minutes.........	48	66	70	39	45	46

*The seeds in this test were taken from the same seed lots used in the test included in Table 1.

ated between 85° and 90° F, while in October, when the second test was carried out, mean temperatures ranged around 70° F.

The failure to devise a mechanical scarifying apparatus which would remove most of the glumes and not crack many of the flat caryopses made acid scarification seem the most practical method of increasing the germination rate of Bahia grass seed. To determine the optimum period of treatment, the experiment presented in Table 2 was set up. The results given in Table 2 show that a 10-minute scarification in concentrated technical H_2SO_4 for the 1937 seed and a 15-minute treatment for the 1936 seed induced a 52 and 48% germination 8 days after planting. Untreated seed germinated 0.3% 3 weeks after they were planted. The reduced germination obtained from treating the 1937 seed for 15 minutes indicates that some of the seeds were injured by this treatment. All of the 1936 seed was completely ripe when harvested, while some of the 1937 seed was slightly green. It is possible that the glumes on these green seeds were not quite so waxy as those on the 1936 seed and hence could not tolerate as much scarifying action.

The effect of several scarification treatments upon the seed of five southern grasses is presented in Tables 3 and 4. From Table 3 it is apparent that treating unhulled Bermuda grass, *Cynodon dactylon*, seed with concentrated HCl for 5 minutes will hasten germination. It is possible that a longer treatment in HCl would increase the germination rate, but 5 minutes in concentrated technical H_2SO_4 apparently killed most of the seeds.

TABLE 3.—*The influence of various seed treatments upon the germination of Vasey grass, Bermuda grass, and carpet grass seed planted in triplicate in steam-sterilized soil in the greenhouse October 10, 1937.*

Treatment	Percentage germination after		
	22 days	32 days	50 days
Commercial Unhulled Bermuda Grass Seed, 1936 Crop			
No treatment	5	11	13
70° C for 17 hours	3	8	11
Conc. HCl, 5 minutes	14	17	20
Conc. technical H_2SO_4, 5 minutes	0.6	0.6	1
Sandpaper scarification*	6	6	7
Vasey Grass Seed Harvested at Tifton, July 5, 1937			
No treatment	57	64	64
70° C for 17 hours	17	22	24
Conc. HCl, 5 minutes	8	11	12
Conc. H_2SO_4, 5 minutes	7	8	8
Conc. technical H_2SO_4, 10 minutes	0.6	0.6	0.6
Sandpaper scarification*	0.3	0.6	0.6
Commercial Carpet Grass Seed, 1936 Crop			
No treatment	66	74	74
Conc. HCl, 5 minutes	19	22	23
Conc. technical H_2SO_4, 5 minutes	29	37	37

*Seeds were rubbed between sandpaper blocks until the caryopses were freed from the glumes.

TABLE 4.—*The influence of various seed treatments upon the germination of Dallis grass and centipede grass seed planted in triplicate in steam-sterilized soil in the greenhouse, December 30, 1937.*

Treatment	Period of treatment in minutes	Percentage germination after		
		11 days	20 days	40 days
Commercial Dallis Grass Seed Produced in 1937 at Hamburg, La.*				
No treatment	—	4	9	17
Conc technical H_2SO_4	5	21	24	29
Conc technical H_2SO_4	10	12	13	15
Conc. technical H_2SO_4	15	4	4	6
Conc technical H_2SO_4	20	2	2	2
35% NaON	5	6	12	22
35% NaOH	10	4	12	30
Centipede Grass Seed Harvested at Tifton, 1937				
No treatment	—	0	3	26
50% HCl	5	0	10	36
50% HCl	10	0	7	37
35% NaOH	5	0	8	34
35% NaOH	10	0	6	25

*No effort was made to separate ergots or empty florets from this seed

Since the glumes enclosing the caryopses of Vasey grass, *Paspalum urvillei*, and carpet grass, *Axonopus affinis*, are not heavy and do not clasp the caryopses tightly, increased germination from scarification would not be expected Table 3 shows that these seeds germinate well without treatment and that those treatments most successful in increasing the germination rate of Bahia grass greatly reduce the viability of carpet grass and Vasey grass seed.

Ray and Stewart[5] working with Dallis grass seed, report that, "Treating the seeds with 37% hydrochloric acid for 3 minutes and no longer than 10 minutes slightly increased their germination". The results presented in Table 4 show that the scarification of Dallis grass seed in concentrated technical H_2SO_4 for a period of 5 minutes may be expected to increase the germination rate materially. That NaOH may also be used as a scarifying agent is suggested by the slightly increased germination percentages obtained from its use.

Centipede grass, *Eremochloa ophiuroides*, is one of the most desirable southern lawn grasses. As the cost of establishing a lawn of this grass by planting stolons (the common practice) is high, an attempt was made in 1937 to harvest a small quantity of seed to be used in the experimental seeding of a lawn. Five pounds of seed were harvested, cleaned, and threshed at a cost of about 40 cents per pound. The delayed germination of these seeds (the caryopses thresh out free from the glumes) and the waxy appearance of the caryopses suggested that mild scarification treatments might hasten the growth of this seed. Table 4 shows that 5- and 10-minute treatments with either 50% HCl or 35% NaOH increased noticeably the germination rate of centipede grass seed.

[5]*Loc. cit.*

On February 22, 1938, the 5 pounds of centipede grass seed, two-thirds of which had been scarified in 50% HCl for 5 minutes, were used to seed 10,000 square feet of lawn surface. A satisfactory stand was obtained from this seeding. The ability of these centipede grass seedlings to compete favorably with crab grass and the other annual weeds during the summer of 1938, the driest on record at Tifton, demonstrates the practicability of establishing lawns of this grass from seed.

Since the crude sulfuric acid used in the manufacture of superphosphate is much cheaper than technical H_2SO_4, it seemed that its merits as a scarifying agent should be investigated. The results of an experiment set up for this purpose are presented in Table 5 and show that a 45- to 60-minute treatment in crude H_2SO_4 and a 10-minute treatment in technical acid were most satisfactory. The injury resulting from the treatment of this lot of seed for 15-, 20-, and 30-minute periods in technical H_2SO_4 demonstrates the care which must be taken when treating seed in this medium Although more time is required to treat Bahia grass seed with crude sulfuric acid, it is undoubtedly a safer and much cheaper scarifying material than technical H_2SO_4 Diluting technical acid with water to approximately 75% H_2SO_4 might render it as safe as crude acid.

TABLE 5 *The effect of technical and crude sulfuric acid scarification upon Bahia grass seed planted in duplicate in steam-sterilized soil in the greenhouse March 3, 1938* *

Treatment	Period of treatment in minutes	Percentage germination after		
		11 days	18 days	25 days
No treatment	—	0 5	14	25
Technical H_2SO_4	10	38	54	54
Crude H_2SO_4	10	1	38	60
Technical H_2SO_4	15	11	12	11
Crude H_2SO_4	15	1	49	68
Technical H_2SO_4	20	0 5	0 5	1
Crude H_2SO_4	20	4	56	70
Technical H_2SO_4	30	0	0	0
Crude H_2SO_4	30	4	48	60
Crude H_2SO_4	45	7	59	73
Crude H_2SO_4	60	8	64	70

*Technical H_2SO_4, specific gravity 1 84, over 94% H_2SO_4, crude H_2SO_4 used in manufacture of super phosphate fertilizer, specific gravity 1 69, about 78% H_2SO_4

A viability test made recently on Bahia grass seed stored at room temperatures for 8 months after its treatment with H_2SO_4 indicates that acid scarification reduces the longevity of the seed and suggests that seed should not be scarified many weeks prior to planting.

In an attempt to make the acid scarification of large quantities of seed practical, the treating apparatus shown in Fig. 1 was devised. In treating the seed, the perforated drum is filled about half full of seed and is rotated slowly in the acid tank for the required period of time. The water tank surrounding the acid tank absorbs the heat generated by the action of the acid on large quantities of seed. In the

treatment of quantities of seed with technical H_2SO_4 without agitation and without a water bath surrounding the acid tank, the heat liberated was sufficient to decompose the acid and kill the seed After the treatment the excess acid is allowed to drain back into the acid tank and the seeds are then washed by rotating the drum in the water tank By running fresh water into the water tank with a hose, the acid left after washing the seed is removed and the temperature of the water is kept down When thoroughly washed, the seeds are removed from the drum and spread in the sun to dry The scarification

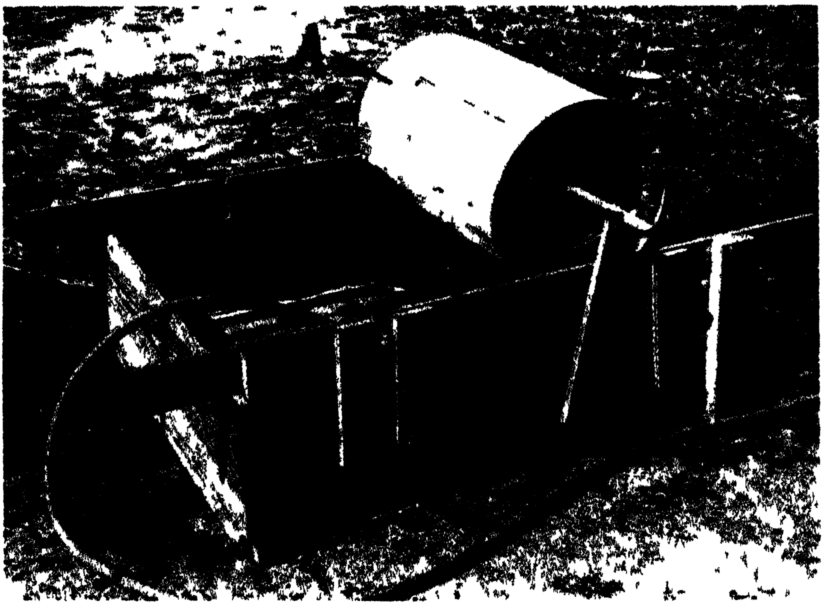

FIG 1 — Acid scarifying machine A seed drum (an old calcium arsenate drum perforated with nail holes), B acid tank (half of a 50 gallon steel barrel), C water tank D standards for resting drum while excess acid is drained back into the acid tank

periods shown to be most satisfactory in small tests are suitable for treating larger quantities of seed with this apparatus Experience with the scarification of different seed lots within the same species proves that the optimum period of treatment for one sample may not be the same for another The wisdom of making several small preliminary treatments before treating large quantities of seed is apparent

The materials used in the construction of the scarifying machine shown in Fig 1 cost about $4 00 By using the acid left after treating the first drum of seed to treat a second lot, it is possible to treat 1 pound of Bahia grass seed with 2 pounds of acid Crude H_2SO_4 can be delivered f.o b Tifton, Georgia, in tank car lots for $10 50 per ton and can be purchased in barrel lots from a local fertilizer plant for 1

cent per pound. A small machine, similar to the one shown in Fig. 1, has been used in treating small lots of seed in the laboratory.

Field experiments set up in 1938 to test the value of acid scarification in the establishment of Bahia grass failed, due to the lack of moisture. During the 1938 growing season, the Tifton area received less than half of its normal rainfall. A shower caused the acid-scarified seed to germinate quite readily, but the subsequent drought killed most of the seedlings.

There is little doubt but that the scarification of the seed of Bahia grass and some other species will increase the chances of their successful establishment. Acid scarification of seed even with the best equipment is not a pleasant task. It is hoped that a satisfactory mechanical method of removing the glumes from Bahia grass and Dallis grass will be found. Until such a method is available it seems that acid scarification may be resorted to with profit.

SUMMARY

1. The large percentage of empty florets, delayed germination and ergot are some of the factors which reduce materially the chances of successfully establishing some of the southern grasses from seed

2. Seed yields taken on 3,500 Bahia plants at Tifton indicate that strains capable of producing 300 to 600 pounds of seed per acre can be found.

3. Seed samples taken from 175 different Bahia grass plants were planted in steam-sterilized soil in the greenhouse and optimum growing conditions were maintained throughout the experiment. Three months after these samples were planted, 35 of them still showed no signs of life and an average viability of 3.2% was obtained in the remaining 140 seed lots.

4. All germination tests were made by planting 100 seeds in duplicate or triplicate in flats of steam-sterilized soil in the greenhouse. Seedling counts were usually made at weekly intervals thus giving the effect of the various treatments on the germination rate.

5. Seventy degrees C dry heat for 4 hours, soaking in water 24 hours with and without reduced pressure, and treatment with concentrated HCl for 5 minutes did not increase the germination of Bahia grass seed significantly.

6. Removing the palea, treating the seed in concentrated technical H_2SO_4 for 5 minutes, and removing both lemma and palea by rubbing the seeds between sandpaper blocks (the dry 1936 seed had to be rubbed so hard that many of the flat caryopses were cracked and killed) hastened germination materially.

7. Higher germination rate obtained with 1-year-old untreated Bahia grass seed as compared with fresh seed suggests that a change favoring germination occurs in storage.

8. Immediate germination of the 1937 seed following removal of the glumes indicates that Bahia grass seed, unlike many other grasses, requires little if any rest period.

9. Scarification of the 1937 seed in concentrated technical H_2SO_4 for 10 minutes and of the 1936 seed for 15 minutes induced a 52 and

48% germination 8 days after planting. Untreated seed germinated 0.3% 3 weeks after they were planted. The reduced germination obtained from treating the 1937 seed for 15 minutes indicates that some of the seeds were injured and that the optimum period of treatment for different lots of seed may not be the same.

10. Treating unhulled Bermuda grass seed with concentrated HCl for 5 minutes increased the germination rate. A 5-minute treatment in concentrated technical H_2SO_4 apparently killed most of the seeds.

11. Seed of Vasey grass and carpet grass germinated readily without treatment. All scarification treatments reduced the viability of these seeds.

12. Scarifying Dallis grass seed with concentrated technical H_2SO_4 for 5 minutes hastened germination materially The value of 35% NaOH as a mild scarifying agent was demonstrated.

13 Five and 10-minute treatments with either 50% HCl or 35% NaOH increased the germination rate of centipede grass seed. The practicability of establishing centipede lawns from seed was demonstrated.

14. Scarification of Bahia grass seed with crude sulfuric acid (used in making superphosphate) for 45 to 60 minutes proved about as effective as a 10-minute scarification in concentrated technical H_2SO_4. Since crude sulfuric acid is much cheaper than technical acid, and since there is less danger of killing the seed from over-treatment, its use is recommended.

15. A viability test on Bahia grass seed stored at room temperature for 8 months after its treatment with H_2SO_4 indicates that acid scarification reduces the longevity of the seed.

16. Field tests made in 1938 demonstrated that acid-scarified Bahia grass seeds germinated quite readily. Prolonged drought subsequent to the emergence of the seedlings killed most of them, making the determination of the effect of seed treatment upon the establishment of the grass impossible.

17. A machine which will facilitate the acid scarification of rather large quantities of seed is described.

THE ADAPTABILITY OF RAPID CHEMICAL TESTS FOR USE IN DETERMINING THE NUTRIENT NEEDS OF SOUTH CAROLINA SOILS[1]

FRANK MOSER[2]

THE nutrient content of soils has been determined for a long time by the use of relatively strong extracting agents. However, no close correlation has been found between the nutrients so determined and the growth response of crops resulting from the addition of available plant nutrients. This lack of correlation has led to the use of weaker extracting agents in determining the availability of soil nutrients.

During the last decade much progress has been made in developing soil tests for determining the availability of plant nutrients culminating in the "rapid or quick test". Morgan (9),[3] Truog (16), Spurway (13), Bray (2, 3), Thornton, Conner and Frazer (14), Hester (7), and others have contributed much to the development of these methods and have created a wide interest in their application to fertilizer practice. According to a recent survey by Thomas (15), the rapid soil test methods are being used by some of the state experiment stations to estimate nutrient deficiencies in soils. The results of these tests are used as a supplementary aid for making fertilizer recommendations to farmers who request that their soil be tested. Most of the emphasis is placed on pH value or lime requirement, and phosphorus and potash availability. Some consideration may also be given such elements as nitrogen, calcium, magnesium, manganese, iron, and aluminum.

Considerable attention has already been given by research workers to the adaptability of these tests to intensive crop production in the Southeast. The work of Hester (7, 8) in Virginia on truck crops has been highly significant. In other sections a fair degree of correlation has been found between yield data and results of rapid tests.

Although these rapid tests have been perfected with respect to chemical procedures and technic, they differ considerably in their adaptability for use under various crop and soil conditions. These different methods have been developed to meet the needs of various local areas and are not necessarily adapted for use in all areas. This study was undertaken to determine which tests are more suitable for use in Piedmont and Coastal Plain areas of South Carolina, and also to determine the reliability of such tests for predicting responses from fertilizer applications.

EXPERIMENTAL PROCEDURE

Soil samples were secured from the plats used for cotton fertilizer experiments near Greer and Gaffney in the Piedmont section and from the Pee Dee and Truck Experiment Station areas in the Coastal Plain. The samples for analysis were

[1]Technical Contribution No 59 from the Department of Agronomy, South Carolina Agricultural Experiment Station, Clemson, S. C. Received for publication August 31, 1938.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 199.

taken during April 1937 before the fertilizer was applied with a soil auger. From 15 to 20 borings to a depth of 7 inches were composited from each 1/20 acre plat for the laboratory analysis. A portion of each sample which was to be used for the rapid tests was passed through a 2-mm sieve, while another portion was passed through a 0.5-mm sieve for the Truog-Myer (17) method which was used as a basis in comparing the tests for determining available phosphorus. The exchangeable potassium was determined by leaching the soil with normal ammonium acetate solution, according to the method proposed by Schollenberger and Dreibelbis (12). The potassium was then determined in the leachate by the sodium cobalti-nitrite method of Volk and Truog (18). These authors found this method to give results in close agreement with crop responses to fertilizer.

The Universal, Purdue, Simplex, LaMotte, and Bray rapid testing methods were chosen for comparison. All the equipment for the various tests was either purchased from the manufacturers or was made up according to published specifications. The above methods differ mainly in the type of extracting solution, concentration, buffer capacity, pH value, procedure for making the test, and method of expressing the results. In order to have a comparable expression of the results, the readings in p.p.m. were made by using a 5-ml aliquot of the soil extract that was made for each test method according to directions.

COMPARISON OF PHOSPHORUS AND POTASSIUM TESTS

Standard stock solutions containing known quantities of phosphorus were prepared to be used with each quick testing method. The procedure was as follows: Into volumetric flasks containing the respective extracting solutions exact quantities of mono-potassium-phosphate were introduced which were sufficient when brought to volume to make solutions containing 0.25, 0.50, 0.75, 1, 2, 5, and 10 p.p.m. of phosphorus. The calibration of the blue color was then made by taking a 5-ml aliquot of each of the standard phosphorus solutions, developing the color according to recommended procedure, and comparing the color intensity with a standard color chart to determine the concentration in p.p.m. of available phosphorus.

The common characteristic of the available phosphorus test methods is the Denigès' (5) colorimetric reaction. These methods all employ an acid extracting solution varying in pH from 1.0 to 4.8. The composition of the extracting solutions vary considerably and some have base exchange properties in addition to the solvent action, while others are primarily dependent upon the solvent action of dilute acids. Minor variations were noted in precipitating reagents used with the different tests, but apparently had no appreciable effect on the results.

For the potassium tests, solutions were prepared in a manner similar to that used in preparing those for the phosphorus tests. Potassium chloride was used to supply potassium in concentrations of 10, 20, 35, 50, 75, and 100 p.p.m. The potassium from a 5-ml aliquot of the stock solutions was then precipitated according to the procedure recommended for potassium.

Some modification of the sodium cobalti-nitrite method for the estimation of available potassium is used in all of the rapid tests used in this investigation. The di-potassium sodium cobalti-nitrite ($K_2NaCo(NO_2)_6$) is precipitated by the addition of either ethyl or iso-propyl alcohol and the turbidity is checked against color charts or by the obscurement of standard width lines. A comparator similar to the one used in the LaMotte portable test kit was graduated in p.p.m. by recording the height of the column where each respective concentration of potassium completely obliterated the black line. The sensitivity of this test diminished very

rapidly in the lower concentrations making potassium difficult to estimate when present in quantities as low as 20 p.p.m.

In some of the soils, a modification was necessary to free the filtrate of ammonia. A separate portion of the filtrate was tested with Nessler's reagent and, if an appreciable amount of ammonia was present 1 ml of 37% formaldehyde was added to the soil extract before the alcohol was added and the p.p.m. determined. The formaldehyde combines with the ammonium salts to form hexamethylenetetramine and thus prevents its interference with the potassium test.

All potassium extracting solutions have many similar characteristics varying in pH value from 3.27 to 4.8 and are dependent upon base exchange reactions for the removal of potassium. The LaMotte and "lac-hi-potash" tests which are commercial products appear to be of the same general type. The symbols used to indicate the p.p.m. of the available nutrients were arbitrarily assigned for convenience. The phosphorus symbols are: Very low, 0 to 0.25 p.p.m.; low, 0.25 to 0.75 p.p.m.; medium, 0.75 to 2 p.p.m.; high, 2 to 5 p.p.m.; very high, 5 p.p.m. and above. The symbols for available potassium were as follows: Very low, 10 to 25 p.p.m.; low, 25 to 35 p.p.m.; medium, 35 to 75 .pp.m.; high, 75 to 100 p.p.m.; very high, 100 p.p.m. and above.

YIELDS

The yields used in this study for correlating growth response to fertilizer application are the 1937 yields and average yields secured from respective plats for entire length of the experiment.

The Gaffney experiment on Cecil sandy loam consisted of three series of 35 1/20-acre plats, cotton appearing on one of the series every year. The yields of seed cotton are averages of all years for the experiment. Likewise the Greer experiment on Cecil sandy clay loam consists ot 35 1/15-acre plats and each fertilizer treatment is repeated in each of three series. The yields are expressed as either the 1937 yield or as an average for all years of the test.

The Pee Dee experiment on Orangeburg fine sandy loam consists of 43 1/10-acre plats. Each fertilizer treatment is repeated in each of three series of plats. The yields of seed cotton are for 1937 and also a 9-year average from 1929 to 1937.

RESULTS OF PHOSPHORUS TESTS

The results from the fertilizer experiment on Cecil sandy loam located at Gaffney are given in Table 1. The data show that each of the rapid test methods indicated approximately the same amount of available phosphorus for identically fertilized plats. When expressed on a p.p.m. basis, there is very little difference in the amount of available phosphorus on plats which received high and low amounts of this element. The yields show a gradual increase in pounds of seed cotton per acre when the phosphorus content of the fertilizer was raised from 0 to 12%, although the 6 and 8% phosphorus applications gave no increase over their preceding increment, yet the yields were substantially higher than on the 4–0–2 plat. This was more evident in the 1937 yields and the 4–8–2 gave the maximum yield of seed cotton. Apparently the fixing power of this soil for phosphorus, together with the increased absorption of phosphorus by the plants in the production of the higher yields of seed cotton, was sufficient to prevent the accumulation of available phosphorus. The phosphorus

obtained by the Truog-Myer method was significantly higher than that shown by the rapid tests and appeared to be associated with the percentage of phosphorus in the fertilizer application.

The results from the fertilizer experiment on Cecil sandy clay loam located at Greer are included in Table 1. This soil type is usually more productive than Cecil sandy loam. In this experiment each of the rapid test methods gave approximately the same amounts of available phosphorus on each plat irrespective of fertilizer treatment. A larger amount of available phosphorus for the Truog-Myer method was found in the plats which had received the higher application of phosphorus fertilizer. The Universal, Simplex, and LaMotte methods gave similar results for the variously treated plats, while the Purdue and Bray methods showed higher concentrations of available phosphorus. Here again no significant differences were found in the amounts of available phosphorus from the plats which received high and low amounts of this element.

Apparently the fixation of phosphorus by the soil and the increased crop growth resulting from the addition of phosphorus in the fertilizer mixture accounted for the lack of available phosphorus. The 1937 yield data substantiated the fact that phosphorus is needed on this soil type for maximum production The data indicate that the amount of available phosphorus in Orangeburg fine sandy loam at the Pee Dee Station is higher than that in the Cecil sandy loam and the Cecil sandy clay loam. The plats on this soil had received an abundant annual phosphate application since 1914. The Truog-Myer method showed a higher concentration of available phosphorus for the plats receiving large amounts of phosphate than for those receiving small amounts The 1937 yields show that the additional increment of phosphorus in the fertilizer above 4% gave lower returns for the increase rate of the application. Although the 4-12-4 gave the highest yield, it gave an increase of 62 pounds of seed cotton over its preceding increment, while the 4-4-4 and 4-6-4 gave 248 pounds and 118 pounds over their respective preceding increment. The cotton yields indicate that the 4-8-4 fertilizer may be used profitably on this soil type. However, the rapid tests show high amounts of available phosphorus present in all plats where the phosphorus applied was over 6%.

In general, the results from the rapid tests for phosphorus were not in close agreement on this soil type. The Purdue and Bray methods gave consistently higher readings than the other three methods. This was especially true for samples from plats which had received higher applications of phosphorus. Conner (4) acknowledges the inadequacies of the Purdue test. He states "the Purdue test is quite reliable on acid clay and loam soils. It tends to show too high on neutral or alkaline soils on light colored sandy soils and on subsoils". The same criticism is true for soils receiving raw rock phosphate. He gives no explanation of the reason underlying this peculiar feature of the test.

Table 1 also shows the amounts of available phosphorus on Bladen fine sandy loam at the Charleston Truck Station. Unfortunately, all phosphate plats were discontinued before samples were secured and

TABLE 1.—*Comparison of various methods of testing the available phosphorus when expressed as p.p.m. from fertilized plats.*

Fertilizer ratio	Pounds, seed cotton, per acre*		pH of soil	Method of determining available phosphorus											
				Truog		Universal		Purdue		Simplex		Bray		LaMotte	
	Ave.	1937		Lbs. acre	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.
Cecil Sandy Loam from the Gaffney Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre															
0-0-0....	288	226	5.18	32	16	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-0-2..	491	313	5.51	60	30	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-2-2....	731	612	5.37	50	25	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-4-2...	847	349	5.30	56	28	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-6-2...	787	721	5.51	60	30	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-8-2.	853	1,025	5.28	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-10-2...	961	897	5.40	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
4-12-2...	967	795	5.30	66	33	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
Cecil Sandy Clay Loam from the Greer Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre with the Exception of the Last Treatment which was 1,400 Lbs.															
-0-0..	479	496	5.55	70	35	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
-0-2..	545	302	5.25	80	40	Low	0.50	Low	0.50	Low	0.50	Low	0.50	Low	0.50
-2-2....	753	439	5.30	80	40	Low	0.50	Low	0.50	Low	0.50	Medium	1.00	Low	0.50
-4-2....	939	806	5.31	80	40	Low	0.50	Low	0.50	Low	0.50	Medium	2.00	Low	0.50
-6-2....	893	539	5.40	100	50	Low	0.50	Low	0.50	Low	0.50	Medium	2.00	Low	0.50
-8-2....	1,027	907	5.41	120	60	Low	0.50	Medium	2.00	Low	0.50	High	4.00	Low	0.50
-10-2...	1,086	1,041	5.51	125	62	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Low	0.50
-12-2...	1,142	1,168	5.30	130	65	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Medium	1.00
-10-2...	1,408	1,481	5.48	180	90	Medium	1.00	High	3.00	Medium	1.00	High	4.00	Medium	1.00

Orangeburg Fine Sandy Loam from the Pee Dee Fertilizer Experiment; Fertilizer Applied at Rate of 1,000 Lbs. per Acre

0-0-0....	654	497	5.50	36	18	Low	0.50	Medium	2.00	Medium	1.00	Medium	1.50	Medium	1.00
4-0-4....	1,218	1,494	5.48	40	20	Low	0.50	Medium	2.00	Low	0.50	High	3.00	Low	.50
4-2-4....	1,549	1,702	5.50	32	16	Medium	1.00	High	5.00	Low	0.50	High	5.00	Medium	1.00
4-4-4....	1,785	1,950	5.48	70	35	High	4.00	Very high	10.00	High	5.00	High	6.00	High	3.00
4-6-4....	1,894	2,068	5.72	90	45	High	4.00	Very high	20.00	High	4.00	Very high	10.00	Very high	6.00
4-8-4....	2,181	2,329	5.61	160	80	High	5.00	Very high	20.00	Very high	6.00	Very high	10.00	Very high	6.00
4-10-4...	2,144	2,350	5.72	120	60	High	5.00	Very high	20.00	Very high	6.00	Very high	10.00	High	5.00
4-12-4...	2,161	2,412	5.68	170	85	Very high	10.00	Very high	40.00	Very high	10.00	Very high	10.00	Very high	6.00
4-16-4...	1,998	2,047	5.62	180	90	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	High	5.00
4-x-4†...	—	2,118	5.95	728	364	Very high	10.00	Very high	40.00	Very high	8.00	Very high	10.00	Very high	6.00

Bladen Fine Sandy Loam from the Truck Experiment Station; Fertilizer Applied at Rate of 2,000 Lbs. per Acre with the Exception of the Last Treatment which was 1,000 Lbs.

5-7-0, Unlimed....	—	4.61	250	125	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Unlimed.....	—	4.63	250	125	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Limed	—	5.55	240	120	Very high	10.00	Very high	40.00	Very high	10.00	Very high	20.00	Very high	10.00
5-7-5, Unlimed. ..	—	5.40	150	75	High	4.00	Very high	20.00	High	4.00	Very high	10.00	High	4.00

*Unpublished data of the S. C. Experiment Station, Agronomy Department.
†Phosphorus derived from raw rock phosphate.

these tests had to be made on soils from potash plats. The data show high amounts of available phosphorus. The amount of available phosphorus by the rapid tests seem to be in accordance with the available phosphorus as shown by the Truog-Myer method in that more p p.m. of phosphorus were found on the 2,000-pound application than on the 1,000-pound application. The same extreme differences which were observed in the case of the Orangeburg fine sandy loam are noticed in the results secured from the Charleston samples when the Purdue and Bray test methods were used. They gave higher concentration of available phosphorus than the other tests. The Universal, Simplex, and LaMotte methods gave high readings also, but the p.p.m. agree for all three.

Anderson and Noble (1) in their recent comparison of several rapid test methods found wide differences between them, but believed that the tests may be a valuable aid for trained agronomists in diagnosing soil needs. Morgan (10) made comparisons of the same rapid testing methods, used in the above experiment, on soils treated with phosphate fertilizers from various sources. Discrepancies similar to those found in the present investigation were reported by Morgan for the Purdue and Bray tests. Other irregularities were also found in this investigation with respect to the Simplex and LaMotte methods, as, for example, the results for the raw rock phosphate plats In this case the LaMotte method gave a very high reading. The Simplex method sometimes gives lower readings than the other methods On the whole, however, all the methods used give approximately the same results. In these studies the Simplex method gave approximately the same p.p m as the Universal and LaMotte methods.

It is concluded from these studies that for South Carolina soils and conditions either the Universal, Simplex, or LaMotte method may be helpful in supplementing existing information for making fertilizer recommendations for phosphorus requirements of soils. However, it is suggested that instead of using small aliquots of the filtrate as directed in some of the tests that the quantity of filtrate for the final reading be increased to 5 ml and the reading made in comparison with permanent color standards or with calibrated color charts

RESULTS OF POTASSIUM TESTS

Table 2 presents the exchangeable and available potassium as determined by base exchange and rapid testing methods on Cecil sandy loam soil, on Cecil sandy clay loam, on Orangeburg fine sandy loam, and on Bladen fine sandy loam. The amount of replaceable potassium is expressed in M. E. per 100 grams of air-dry soil.

For the Cecil sandy loam the replaceable potassium is extremely low, varying from 0 03 to 0.12 M. E., while an appreciable increase occurs in exchangeable potassium where the potash in the fertilizer application was increased. The moderate application of fertilizer, which was at the rate of 600 pounds per acre, evidently did not supply much more potash than was required for the cotton crop. The yields showed very insignificant increases of seed cotton when the fertilizer ratio was changed from a 4-10-0 to a 4-10-4 except on the 4-10-1

plat which may be attributed to an unavoidable soil variation of terraced fields. Low availability of potassium was indicated by the rapid tests and small differences were found in the readings for soil on the plats which received the various amounts of potash fertilizer. The 4-10-4 plat gave a small increase in yield and had a medium reading for available potassium. Likewise this plat had the largest amount of replaceable potassium. The only reading of the rapid tests that may have expressed a doubtful response is the 4-10-4 plat. However, the 1937 yields show no significant differences in yields of seed cotton between the potash and no potash plats, while on the contrary the rapid tests show low availability

The available potassium content of Cecil sandy clay loam is greater than on the Cecil sandy loam which is evidenced by the readings of the rapid tests Likewise, the replaceable potassium content was considerably higher Thus the rapid tests are capable of showing increases in potassium

The yields of seed cotton on Cecil sandy clay loam show that potash fertilizer is responsive in stimulating cotton production. The plats that received the 4 10-1, 4 10-2, and 4 10-3 plats produced 94, 127, and 192 more pounds of seed cotton, respectively, than the no-potash treatment. The 1937 yields show more significant responses from potash fertilizer than the average yields as these same plats gave increases of 101, 204, and 376 pound of seed cotton, respectively, over the 4 10 0 fertilizer treatment. The rapid tests show no difference in available potassium content of the soil on those plats which received the different rates of potash. However, no noticeable difference was expected since the difference in the added potash between 0 and 4% plat amounted to only 24 pounds per acre.

Where the fertilizer application had been increased from 600 to 1400 pounds per acre, the yield was materially increased and some of the rapid tests showed a slightly higher concentration of available potassium This indicated that the application of 1,400 pounds per acre supplied somewhat more potassium than was required for crop growth resulting in an increase in the reserve or replaceable potassium of the soil. In the recent work by Goss and Prince (6), results of similar trend were secured with the rapid tests on some of the field and cylinder experiments at the New Jersey Experiment Station. They found that all plats fertilized with the larger amounts of minerals gave increases in available potassium corresponding with the quantity of fertilizer used.

According to the rapid tests used in this instance, the available potassium of the Orangeburg fine sandy loam was very low indicating a deficiency of potash in this soil. There had been an increase in yield where the potash in the fertilizer application was raised from 0 to 8% The highest yield of cotton was received from the 4-8-6 fertilizer. The increases for successive increments drop off very sharply where the potash is applied above 2% in the application, but all increments gave significant increases over the 4-8-0 treatment. As might be expected, however, the highest amount of replaceable potassium was found on the plat which had received the 4-8-8 fertilizer.

TABLE 2.—*Comparison of various methods of testing the available potassium when expressed as p.p.m.*

Fertilizer ratio	Pounds, seed cotton, per acre*		pH of soil	Method of determining available potassium												
				Exchangeable			Universal		Purdue		Simplex		Bray		LaMotte	
	Ave.	1937		M.E./100 grams soil	Lbs./acre	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.	Symbol	p.p.m.
Cecil Sandy Loam from the Gaffney Cooperative Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs per Acre																
0-0-0....	288	226	5.18	0.03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-10-0....	931	838	5.40	0.04	32	16	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-10-1...	867	622	5.00	0.05	40	20	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-10-2....	957	922	5.40	0.06	46	23	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-10-3....	998	1,448	5.21	0.08	62	31	Low	25	Low	30	Low	30	Low	30	Low	25
4-10-4....	1,078	907	5.00	0.12	94	47	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
Cecil Sandy Clay Loam from the Greer Cooperative Fertilizer Experiment; Fertilizer Applied at Rate of 600 Lbs. per Acre with the Exception of the Last Treatment which was 1,400 Lbs.																
0-0-0.....	479	496	5.55	0.11	86	43	Medium	40	Medium	40	Low	30	Low	30	Medium	40
4-10-0 ..	908	492	5.40	0.11	86	43	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-1....	1,002	593	5.45	0.14	110	55	Medium	40	Medium	40	Low	30	Medium	40	Medium	40
4-10-2,..	1,035	696	5.48	0.14	110	55	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-3....	1,100	868	5.50	0.15	118	59	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
4-10-4...	954	797	5.39	0.17	133	66	Medium	40	Medium	50	Medium	50	Medium	40	Medium	40
4-10-2 ...	1,408	1,481	5.48	0.19	148	74	Medium	50	Medium	60	Medium	50	Medium	40	Medium	50

Orangeburg Fine Sandy Loam from the Pee Dee Fertilizer Experiment. Fertilizer Applied at Rate of 1 000 Lbs per Acre

0-0-0	654	497	5 50	0 03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-0	1 286	844	5 47	0 03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-1	1 772	1 827	5 55	0 03	24	12	Very low	10	Very low	10	Very low	10	Very low	10	Very low	10
4-8-2	1 903	1 683	5 33	0 06	47	23	Very low	10	Very low	20	Very low	20	Very low	20	Very low	20
4-8-3	1 962	1,913	5 56	0 07	55	27	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-4	2 024	2,180	5 65	0 08	62	31	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-5	2 160	2 254	5 69	0 09	70	35	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8-6	2 181	2,272	5 50	0 08	62	31	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20
4-8 8	1,947	2 516	5 50	0 12	94	47	Very low	20	Very low	20	Very low	20	Very low	20	Very low	20

Bladen Fine Sandy Loam from the Truck Experiment Station. Fertilizer Applied at Rate of 2 000 Lbs per Acre with the Exception of the Last Treatment Which was 1 000 Lbs per Acre

5-7-0, Unlimed		—	4 61	0 12	94	47	Medium	40	Medium	40	Medium	40	Medium	40	Medium	40
5-7 5, Unlimed		—	4 63	0 22	172	86	Medium	70	Medium	70	Medium	50	Medium	70	Medium	60
5-7-5 Limed		—	5 55	0 29	226	113	Very high	150	Very high	150	High	100	Very high	150	Very high	160
5-7-5, Unlimed		—	5 40	0 14	110	55	Medium	40	Medium	60	Medium	40	Medium	40	Medium	60

*Unpublished data of the S C Experiment Station Agronomy Department

The results of tests of four plats on Bladen fine sandy loam at the Charleston Truck Experiment Station are also presented in Table 2. Three plats had been fertilized for a period of 5 years at the rate of 2,000 pounds and one plat at the rate of 1,000 pounds per acre of commercial fertilizer. The tests showed that the amount of available potassium was considerably higher in these soils than in any of the other soils tested in this study. The amount of available potassium was greater in the plats which had received the 5-7 5 than in the one which had received the 5-7-0 fertilizer. Both the unlimed and limed plats which had received the 5-7-5 fertilizer had higher amounts of available potassium than the plats fertilized with a 5-7-0 fertilizer. The individual tests showed fairly good agreement for these plats, except that the Simplex method gave a slightly lower reading

The replaceable potassium content of the Cecil sandy loam, Cecil sandy clay loam, and Orangeburg fine sandy loam soils studied in this experiment and for which yield data are available, varied from 0.03 to 0.19 M. E. per 100 grams of air-dry soil, or from 12 to 74 p.p.m. Yield responses were secured on the plats where the replaceable potassium was within this range. Murphy (11), working on Oklahoma soils, found that crop responses were obtained from application of potash to soil having less than 60 p.p.m. of available potassium while some increased yields resulted on soils having as high as 79 p.p.m. of available potassium.

The five methods used in this study for testing available potassium on the four soil types show similar results. It is therefore concluded that any one of these methods show about the same amount of available potash on soil having identical fertilizer treatment. However, since the majority of the soils used in this investigation had a low supply of available potassium, it might be advisable to investigate the reliability of the methods for testing soils containing larger amounts of available potassium. If the results secured in these tests are indicative of the general condition of South Carolina soils they are in need of potash.

SUMMARY

Comparisons of the Universal, Purdue, Simplex, Bray, and LaMotte tests were made to determine their adaptability for use in testing South Carolina soils.

All readings of the tests were made comparable by using a 5-ml aliquot of the soil extract for reading the results of each test in p.p.m. Each of the tests had been previously standardized by checking against known concentrations of phosphorus or potassium.

The data show that the Universal, Simplex, and LaMott testing methods may be used for estimating the phosphorus needs of soil, but the Purdue and Bray tests are not very satisfactory for this purpose for South Carolina soils.

The results also show that all the methods tested show about the same amount of available potassium on soil having approximately the same M. E. of replaceable potassium. The 1937 yields show that on Orangeburg fine sandy loam a good response for potash fertilizer

was obtained on plats where the rapid tests indicated a low availability. The Cecil sandy clay loam gave significant yield increases for potash fertilization, while a medium amount of available potassium or doubtful response was indicated by rapid tests; whereas, a negative correlation was found between yields and the rapid tests on Cecil sandy loam.

LITERATURE CITED

1. ANDERSON, M. S., and NOBLE, W. M. Comparison of various chemical quick tests on different soils. U.S.D.A. Misc. Pub. 259. 1937.
2. BRAY, R. H. A field test for available phosphorus in soils. Ill. Agr. Exp. Sta. Bul. 24. 1929.
3. ———. A test for replaceable and water soluble potassium in soils. Jour. Amer. Soc. Agron., 24:312-316. 1932.
4. CONNER, S. D. What rapid tests have shown about Indiana soils. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
5. DENIGES, G. An extremely sensitive test for phosphorus and arsenic and its application Comptes Rendus, 171:802. 1920.
6. GOSS, D. M., and PRINCE, A. L. Results of rapid tests to soils of known fertilizer treatment. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
7. HESTER, J. B. Experiments with rapid chemical soil tests for vegetable crops. Proc. Ann Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
8. ———. Microchemical soil tests in connection with vegetable crop production. Va. Truck Exp. Sta. Bul. 82. 1934.
9. MORGAN, M F. The Universal soil testing system. Conn State Agr. Exp. Sta. Bul. 372 1935.
10. ———. The variance of methods of testing for phosphorus on soils previously treated with different phosphate fertilizer. Proc. Ann. Meet. Com. Fert., Amer. Soc. Agron., Dec. 1935.
11. MURPHY, H. F The replaceable potassium content compared with field response to potash fertilization of some Oklahoma soils. Jour. Amer. Soc. Agron., 26:34-37. 1934.
12. SCHOLLENBERGER, C. J., and DREIBELBIS, F. R. Analytical methods in base exchange investigations on soils. Soil Science, 30:161-173. 1930
13. SPURWAY, C. H. Soil testing. Mich. Agr. Exp. Sta. Tech. Bul. 132. 1935.
14. THORNTON, S. F., CONNER, S. D., and FRAZER, R. R. The use of Rapid Chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Agr. Exp. Sta. Circ. 204. 1936.
15. THOMAS, R. P. The use of rapid soil tests in the United States. Jour. Amer. Soc. Agron., 28:411-419. 1936.
16. TRUOG, E. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874-882. 1930.
17. ——— and MEYER, A. H. Improvements in the Deniges Colorimetric method for phosphorus and arsenic. Ind. and Eng. Chem., Anal. Ed., 1: 136-139. 1929.
18. VOLK, N. J., and TRUOG, E. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26:537-546. 1934.

EFFECTIVENESS OF CONTACT SPRAYS IN THE CONTROL OF ANNUAL WEEDS IN CEREAL CROPS[1]

B. N. SINGH AND K. DAS[2]

SINCE the accidental discovery by the French vine grower L. Bonnet, the control of weeds by herbicides as a quick and labor-saving method has been widely resorted to. The pioneer researches of Korsmo (6)[3] and Rebaté (7) and various trails in Europe and America have brought sulfuric acid, sulfates of copper and iron, arsenic compounds, and other chemicals into prominence as efficient contact sprays. Besides large variations in the efficiency of the different sprays, their effectiveness depends largely on the meteorological conditions prevailing at the time of spraying. Thus, successful results are expected if spraying is carried out in fine weather with favorable temperature and humidity.

The experiments so far reported are of local interest since weather conditions vary widely from place to place, making it difficult to arrive at any definite conclusion. Moreover, little knowledge exists about the use of these herbicides in the tropics where weather conditions differ widely from those obtaining in the temperate regions. To elucidate relevant information pertaining to the problem of the physiology and control of weeds as it relates to the tropics, work has been in progress at the Institute of Agricultural Research at Benares, India, for some time past. In the present paper are described the results of experiments on the effectiveness of a few of the more important contact sprays in the control of annual weeds in a cereal crop. Besides the degree of control, the relation of the yield of the crop to the reduction in weed density, the degree of injury to the cereal crop, the time of spraying, the stage of growth of the weeds, and the souring effect on soil due to sulfuric acid spraying have been studied.

EXPERIMENTAL PROCEDURE

The effectiveness of three sprays, *viz.*, sulfuric acid, copper sulfate, and ammonium thiocyanate, was tested. Three separate experiments on three adjacent fields with an uniform history of crop production and manuring were conducted for the three sprays in randomized blocks replicated four times, the size of the plats being 1/50 acre with borders 2 feet in width between them. Clean seeds of wheat (Pusa 4) were sown in the third week of October of 1936.

The spray solutions were applied at the rate of 100 gallons per acre by means of a Knapsack sprayer. One set of plats was sprayed when the weeds were in the young seedling stage, roughly when the fourth true leaf had developed. The wheat at this stage was nearly 6 to 8 inches in height, but no active tillering had proceeded. The second set of plats was sprayed nearly 2 weeks after the first spraying. On an average six leaves were observed on the weeds while tillers had formed in the wheat.

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[1]Contribution from the Institute of Agricultural Research, Hindu University, Benares, India. Received for publication October 31, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 208.

The effect of the sprays were observed on the three more abundant weeds, *viz.*, *Chenopodium album*, *Anagallis arvensis*, and *Euphorbia dracunculoides*. The degree of weed infestation and the control obtained by the various treatments were based on the counts of the number of individuals of these three species in 20 random samples of 1-square foot quadrats in each plat recorded between 2 to 3 weeks after spraying. The differences in density between the control and the treated plats were taken as the measure of weed reduction. Estimates of density in each sample before and after the treatments, although afforded possibilities of greater accuracy in the analysis of the data by the covariance method as was adapted in a previous contribution (9), had to be discarded because of the elaborateness in the collection of data involving much time and labor.

The variance of the estimates of density (number of individuals per square foot) being discontinuous, statistical computations to compare the significance of the different treatments on the reduction in weed density have been confined to the square roots of the numbers of individuals per unit area (9).

DATA AND DISCUSSION

EFFECT ON WEEDS

Data of the three experiments on the control of weeds by sulfuric acid, copper sulfate and ammonium thiocyanate (Tables 1, 2, and 3) indicate that all three weeds were significantly reduced in their densities as compared to the control plants. The degree of reduction, however, varied for the different weeds and the different chemicals depending upon the morphological peculiarities and the relative hardiness of the weed species. Wetting of the tissue and penetration of the spray solutions were difficult to attain in the case of the leaves of *C. album* due to the waxy covering, which explains the lower degree of control in the case of this weed This necessitates the use of a wetting agent since the effective control of weeds depends primarily upon the quantity of spray solution adhering on the plant tissue.

Of the different treatments, hand-weeded plats have shown the highest reduction in the density of individuals of all the three weed species. A comparison of the square roots of densities per unit area by the critical differences[4] indicate that only in the case of *C. album* hand-weeded plats showed a significant reduction in weed density as compared to the other treated plats. This is apparent since none of the chemicals used has brought about a very high degree of control of this weed. When, however, *E. dracunculoides* was sprayed either with 2.5% copper sulfate solution at the fourth leaf stage (Table 2) or 5% ammonium thiocyanate solution at the later stage (Table 3), the reduction of weed density was not high and, therefore, significant differences with the hand-weeded plats were evident.

Since three separate experiments were conducted for the three chemicals, it is not possible to make a direct comparison of their effects. Although the differences between the effects of the three chemicals are not very striking, sulfuric acid appeared to be more

[4]For comparison of the effects between the different treatments (excluding control), the critical differences obtained after eliminating the data of the control plats are estimated and are taken as the measure of significance.

TABLE I.—*Control of annual weeds in wheat with sulfuric acid spray.*

Treatment				Response of weeds					
				C. album		*A. arvensis*		*E. dracunculoides*	
No.	Concentration %	Stage of growth of weed	Time of application	Square root of density per sq. ft.	Degree of control %	Square root of density per sq. ft.	Degree of control %	Square root of density per sq. ft.	Degree of control %
1	Control	—	—	5.31	—	3.56	—	2.90	—
2	Hand-weeded	—	—	1.05	—	0.71	—	0.59	—
3	7.5	4-leaf	Morning	3.13	65.31	1.41	84.25	10.02	87.57
4	10.0	4-leaf	Morning	2.94	69.38	1.14	89.76	0.94	89.34
5	12.5	4-leaf	Morning	2.44	78.93	1.09	90.55	0.74	93.49
6	7.5	4-leaf	Evening	3.26	62.47	1.38	85.03	0.87	91.12
7	10.0	4-leaf	Evening	3.02	67.61	0.95	92.91	0.67	94.67
8	12.5	4-leaf	Evening	2.78	72.56	0.89	93.70	0.806	92.30
9	7.5	2 weeks later	Morning	3.37	59.82	1.05	91.73	1.07	86.39
10	10.0	2 weeks later	Morning	3.12	65.48	0.84	94.48	0.92	89.94
11	12.5	2 weeks later	Morning	2.58	76.46	0.78	95.27	0.59	95.85
Significant difference (P = .05)				2.028		1.18		0.928	
Significant difference*				1.13		1.01		0.798	

*This critical difference is obtained after eliminating the data of the control plats

TABLE 2 *Control of annual weeds in wheat with copper sulfate spray*

No	Concentration %	Stage of growth of weed	Time of application	*C album* Square root of density per sq ft	*C album* Degree of control %	*A arvensis* Square root of density per sq ft	*A arvensis* Degree of control %	*E dracunculoides* Square root of density per sq ft	*E dracunculoides* Degree of control %
1	Control	—	—	5 5		3 77	—	3 54	—
2	Hand weeded	—		1 48		1 18	—	1 04	—
3	2 5	4 leaf	Morning	3 68	55 24	1 85	76 17	2 02	67 64
4	4 0	4 leaf	Morning	3 46	60 35	1 76	78 23	1 79	74 58
5	5 0	4 leaf	Morning	3 38	62 26	1 63	81 41	1 86	72 47
6	2 5	4 leaf	Evening	3 41	61 47	1 71	79 53	1 68	77 53
7	4 0	4 leaf	Evening	3 24	65 23	1 58	82 61	1 60	79 63
8	5 0	4 leaf	Evening	3 08	68 57	1 48	84 76	1 52	81 74
9	2 5	2 weeks later	Morning	3 64	56 29	1 79	77 65	1 83	73 48
10	4 0	2 weeks later	Morning	3 42	61 26	1 62	81 65	1 57	80 49
11	5 0	2 weeks later	Morning	3 32	63 39	1 68	80 29	1 45	83 37
Significant difference (P = 05)				2 018		1 82		1 13	
Significant difference*				0 968		0 824		0 8	

*This critical difference is obtained after eliminating the data of the control plat

TABLE 3 *Control of annual weeds in wheat with ammonium thiocyanate spray*

No	Concentration %	Stage of growth of weed	Time of application	*C album* Square root of density per sq ft	*C album* Degree of control %	*A arvensis* Square root of density per sq ft	*A arvensis* Degree of control %	*E dracunculoides* Square root of density per sq ft	*E dracunculoides* Degree of control %
1	Control	—		6 5		4 4		3 1	—
2	Hand weeded	—	—	1 6		1 1		0 71	—
3	5	4 leaf	Morning	4 29	56 34	1 63	86 24	1 27	83 21
4	10	4 leaf	Morning	4 08	60 52	1 28	91 54	0 91	91 37
5	15	4 leaf	Morning	3 ,6	66 37	0 8	96 67	0 51	97 26
6	5	2 weeks later	Morning	4 39	54 29	1 83	82 72	1 48	77 29
7	10	2 weeks later	Morning	4 16	58 91	1 66	88 75	1 21	84 81
8	15	2 weeks later	Morning	3 86	64 75	0 95	95 28	0 74	94 27
Significant difference (P = 05)				2 06		1 216		0 77	
Significant difference*				1 2		0 848		0 70	

*This critical difference is obtained after eliminating the data of the control plats

effective than either copper sulfate or ammonium thiocyanate, while the latter appeared to be better than the former.

The effectiveness of spraying appears to increase as the concentration of the spray solutions is increased (Tables 1, 2, and 3). Such a differential behavior is only apparent since the differences between the treatments are not statistically significant. There is, however, a significant difference in the density of *E. dracunculoides* when 5 and 15% strengths of ammonium thiocyanate solutions are used.

The relation of temperature and humidity to the loss of the spray solution by evaporation has long been recognized. The data on the control of the three weeds by sulfuric acid and copper sulfate show that the effectiveness of these compounds for field purposes is unaltered when the plants sprayed in the morning are exposed to the sun with high temperature and low humidity or when the weeds are sprayed in the evening with temperature and humidity factors less conducive to evaporation, contrary to Aslander's (1) pot culture experiments conducted under controlled conditions A practical program of weed control by chemicals must take into account these factors, but judging from the present evidence not much of a loss of efficiency may be expected if in winter months spraying is carried out in the morning. Facts have to be empirically determined for the different seasons of the year.

The two stages of the growth of the weeds under study have little significance in the matter of their control The second spraying failed to bring about any marked difference in the degree of control apparently because both the morphological and the physiological conditions of the plants had not undergone any marked change. With two exceptions when thiocyanate solution was sprayed on *E. dracunculoides* (Table 3), this is true for all the three weeds Although the two stages of the growth of the weeds did not appear to be of much significance in the matter of their control in the present experiments, delayed spraying must not be advocated since the early stimulus given to the wheat crop in the severe set-back to the associated weeds will carry the crop plants beyond weed competition.

A serious draw back in the chemical control of weeds, however, is the power of regeneration of certain weeds. When only the tip portions are killed, lateral branches from the base near the soil surface are seen to grow profusely in the case of *C. album*. A considerable portion of the stand of this weed is often formed by such regenerated plants. Such regenerations were not usually observed in the case of the other two weed species.

EFFECT ON CROP

A perusal of the data on the yield of wheat for the three experiments (Table 4, 5, and 6) shows that all the treated plats gave higher yield per acre as compared with the control plats, although the differences in the majority of the cases are not statistically significant. Significant increases in the grain yield in the hand-weeded plats were obtained in the experiments with sulfuric acid and copper sulfate. The hand-weeded plats of the copper sulfate series have also given the highest yield (Table 5). The majority of the sulfuric acid

and copper sulfate treated plats do not, however, show a significant increase in grain yield as compared with the control plats (Tables 4 and 5) In the thiocyanate experiments all the treatments produced significantly higher yields except when the lowest concentration of the solution was used (Table 6) This significant increase may be traced to the combined effect of the elimination of weed competition and the extra nutrition provided That the second factor is potent is corroborated by the increased yield in the plats treated with higher concentrations of this solution

TABLE 4 *Yield of wheat when spraying with sulfuric acid for weed eradication*

No	Treatment: Concentration, %	Treatment: Stage of growth of weed	Treatment: Time of application	Weed density number of plants per sq ft: *C album*	Weed density number of plants per sq ft: *L arvensis*	Weed density number of plants per sq ft: *I dracunculoides*	Yield of grain per acre cwt
1	Control			28 25	12 70	8 45	9 16
2	Hand weeded			2 10	0 50	0 35	11 19
3	7 5	4 leaf	Morning	9 80	2 00	1 05	10 81
4	10 0	4 leaf	Morning	8 65	1 30	0 55	11 01
5	12 5	4 leaf	Morning	5 95	1 20	0 90	10 60
6	7 5	4 leaf	Evening	10 60	1 90	0 75	10 86
7	10 0	4 leaf	Evening	9 15	0 90	0 45	10 92
8	12 5	4 leaf	Evening	7 75	0 80	0 65	11 25
9	7 5	2 weeks later	Morning	11 35	1 05	1 15	10 79
10	10 0	2 weeks later	Morning	9 75	0 70	0 85	10 69
11	12 5	2 weeks later	Morning	6 65	0 60	0 35	10 94
Significant difference (P = 05)							1 814

TABLE 5 *Yield of wheat when spraying with copper sulfate for weed eradication*

No	Treatment: Concentration, %	Treatment: Stage of growth of weed	Treatment: Time of application	Weed density plants per sq ft: *C album*	Weed density plants per sq ft: *L arvensis*	Weed density plants per sq ft: *F dracunculoides*	Yield of grain per acre cwt
1	Control	—		30 25	14 30	12 60	9 67
2	Hand weeded	—		2 20	1 40	1 10	10 77
3	2 5	4 leaf	Morning	13 54	3 41	4 08	10 42
4	4 0	4 leaf	Morning	11 99	3 11	3 20	10 14
5	5 0	4 leaf	Morning	11 42	2 66	3 47	10 50
6	2 5	4 leaf	Evening	11 66	2 93	2 83	10 19
7	4 0	4 leaf	Evening	10 52	2 49	2 57	10 74
8	5 0	4-leaf	Evening	9 51	2 18	2 30	10 60
9	2 5	2 weeks later	Morning	13 22	3 20	3 34	10 17
10	4 0	2 weeks later	Morning	11 72	2 60	2 10	10 46
11	5 0	2 weeks later	Morning	10 07	2 82	2 46	10 56
Significant difference (P = 05)							0 834

TABLE 6.—*Yield of wheat when spraying with ammonium thiocyanate for weed eradication.*

Treatment				Weed density, plants per sq. ft.			Yield of grain per acre, cwt.
No	Concentration, %	Stage of growth of weed	Time of application	*C album*	*A arvensis*	*E dracunculoides*	
1	Control	———	———	42.25	19.36	9.61	9.24
2	Hand-weeded	———	———	2.56	1.21	0.50	10.63
3	5	4-leaf	Morning	18.45	2.67	1.62	10.54
4	10	4-leaf	Morning	16.67	1.64	0.83	12.10
5	15	4-leaf	Morning	14.21	0.64	0.26	12.87
6	5	2 weeks later	Morning	19.31	3.34	2.18	10.67
7	10	2 weeks later	Morning	17.36	2.75	1.46	11.51
8	15	2 weeks later	Morning	14.90	0.91	0.55	12.62
Significant difference ($P = .05$)							1.51

It is difficult to evaluate the relationship between the increase in yield and the reduction in the density of weeds. The increased yield on the hand-weeded plats in the sulfuric acid and copper sulfate experiments is significant, since it was on these plats that the competition of the crop plants with the weeds was at its minimum From the inconsistency in the hand-weeded plats of the thiocyanate experiment it would appear that a reduction in weed density did not necessarily result in a higher yield of wheat. It might be mentioned, however, that the weed densities in the present experiments were not alarmingly large and further evidence should be collected before generalizing on the effect upon crop yield of the elimination of weeds Among the contributory factors, the specific relation of the different weed species should also be taken into consideration.

The injury done to the crop appeared to depend upon the physiological stage of the growth of the crop and the relative toxicity of the spray solutions Since toxicity increased with the concentration of the spray solution, the degree of injury also parallelled concentration. The stage of growth of the crop was also an important factor While young plants with tender leaves were more susceptible to injury, the leaves had greater power of recovery and the longer growing period provided an opportunity for the plant to re-establish itself. With increase in age of the crop, however, the leaf, though not so tender, exposed a larger surface thereby increasing the possibility of greater injury. The record of the time taken for recovery by the crop shows that, when weaker solutions were applied earlier, crop plants took 12 to 15 days to recover, but when higher concentrations of the solutions were used another week elapsed before the plants assumed normal appearance. Greater injury was associated with the application of acid spray. The manifestations of toxicity were also rapid in the plants receiving this spray. Besides the possibility of greater injury to the crop plants, another danger of delayed spraying was the longer time required for the plants to recover.

EFFECT OF ACID ON SOIL REACTION

The question is often raised whether sulfuric acid spraying tends to make the soil "sour". With a view to obtain information on this point data on the soil acidity of the acid-sprayed plats have been collected.

The pH values of the soil from the several plats were determined a week after the first treatments were carried out. Random samples of soils were taken to a depth of 6 inches and were properly mixed to make composite and representative samples. The pH values of the soil suspensions were estimated potentiometrically using the quinhydrone electrode. The data thus obtained were analysed statistically by the analysis of variance method. For the second set of plats receiving the treatments at a later date samples were collected before a week after the spraying was carried out. The mean pH values and their standard errors for each of the treatments before and after spraying were computed, so also the standard errors of the difference of the mean pH values to compare the significance of the results.

A perusal of the data (Table 7) indicate that, although a lowering of the pH values in the treated plats is apparent, the differences with the control or hand-weeded plats are not statistically significant The standard errors calculated on the pH differences in the case of the plats receiving the acid spray at a later date (Table 8) also point to the same conclusion Thus there was no significant souring effect on the soil of this locality due to the use of sulfuric acid as a weed killer. The present evidence is consistent with the observations of

TABLE 7 *Soil reaction after sulfuric acid spray applied at the 3-leaf stage of development of the weed plants*

Treatment		Mean pH*	Critical difference
Concentration of solution, %	Time of application		
Control	------	5 4	---
Hand-weeded	------	5 5	-
7.5	Morning	5 1	—
10.0	Morning	4 9	
12.5	Morning	4 8	0 74
7.5	Evening	5 0	—
10.0	Evening	4 8	-
12.5	Evening	4 9	-

*Mean of several pH figures

TABLE 8.—*Soil reaction after sulfuric acid spray applied 2 weeks later than in Table 7.*

Treatment		pH before spraying	pH after spraying	Difference in pH values
Concentration of solution, %	Time of application			
7.5	Morning	5.5±0.136	5.2±0.072	0.3±0.153
10.0	Morning	5.2±0.084	4.9±0.114	0.3±0.141
12.5	Morning	5.3±0.116	4.9±0.220	0.4±0.248

Brioux (5). Even if there be any slight increase of acidity of the soil soon after the acid spraying is carried out, the remarkable buffering capacity of the plants (10) may be relied upon to adjust such changes, and it may not, therefore, be necessary to apply a heavier dose of lime than that required under ordinary conditions of farming.

SUMMARY AND CONCLUSIONS

Replicated experiments on the control of annual weeds in a wheat field of known history by the use of three contact sprays, namely, sulfuric acid, ammonium thiocyanate, and copper sulfate, indicate that the degree of control differed with the different weeds and herbicides. *Anagallis arvensis* and *Euphorbia dracunculoides* showed higher degrees of reduction than *Chenopodium album*, explainable on the morphological peculiarities and the relative hardiness of the weeds as well as on the quantity of spray solution adhering on the surface, while the herbicides showed effectiveness in the decreasing order of sulfuric acid, ammonium thiocyanate, and copper sulfate.

Contributory factors that apparently aided in the effectiveness of the treatments are the concentration of the herbicides, the time of their application, the stage and development of the plants, the leaf area exposed, and the temperature and humidity of the atmosphere. On a statistical examination of the data, however, significant differences were not observed.

The yield of the grain tended to increase with a reduction in weed density, but the differences with the control plats were not always statistically significant. Spraying with a higher concentration of ammonium thiocyanate solution gave significantly better result because of the addition of extra nutrients besides the elimination of weed competition.

Sulfuric acid spraying did not make the soil sour. The small differences in pH, if any, were not significant.

LITERATURE CITED

1. ASLANDER, ALFRED. Sulphuric acid as a weed spray. Jour. Agr. Res., 24:1065-1091. 1927
2. BALL, W. E., and FRENCH, O. C. Sulphuric acid for control of weeds. Calif. Agr. Exp. Sta. Bul 596. 1935
3. BLACKMAN, G. E. The control of annual weeds in cereal crops by dilute sulphuric acid. Emp. Jour Exp. Agr., 2:213-227. 1934.
4. ——— ——— and TEMPLEMAN, W. G. The eradication of weeds in cereal crops by sulphuric acid and other compounds. Jour. Agr. Sci., 24:368-390. 1936.
5. BRIOUX, C. Compt rend Acad Sci., 179:74. 1924.
6. KORSMO, E Unkrauter im Ackerbau der Newzeit. Berlin: Verlag Von Julius Springer 1930.
7. RABATÉ, E. La destruction de Mauvais Herbes. Paris: Librairie l Academie d Agriculture 1927.
8. SINGH, B N., DAS, K., and CHALLAM, G. V. Effectiveness of cultural treatments in the control of weeds. Emp Jour. Exp. Agr., 5:63-68. 1937.
9. ——— ———, ——— ———. Effectiveness of spraying with fertilizers for control of weeds on arable land. Jour. Amer. Soc. Agron., 30:465-474. 1938.
10. ——— ——— and MITRA, G P. Plant growth in relation to hydrogen ion changes in its medium. Ind. Jour. Agr. Sci., 7:327-348. 1937.

INHERITANCE OF FLOWER COLOR IN ALFALFA[1]

ROBERT LEPPER, JR., AND T. E. ODLAND[2]

STUDIES on the inheritance of certain characters in alfalfa were begun at the Rhode Island Agricultural Experiment Station in 1929. The chief purpose in mind was the obtaining of strains of alfalfa that would be more suitable to local conditions than those now available. On our naturally acid soils, alfalfa is usually short-lived and often difficult to get established. This is especially so when it is attempted to grow it in pure culture. When grown in mixture with grasses and clovers, it seems to thrive much better. If a strain could be produced that would be better adapted to our soil and climatic conditions, alfalfa would no doubt assume a place of more importance on Rhode Island dairy farms So far, most of the breeding work with alfalfa has been done in the midwestern states where the crop is better adapted than it is in the eastern United States and where the problems of growing the crop are considerably different.

Selections have been made from a number of varieties and strains of alfalfa. These selections have been selfed for the purpose of obtaining pure breeding material to be used in crossing as well as for the study of the influence of selfing Selections have been made from Grimm, Canadian Variegated, Hardigan, Ladak, Hansen, Cossack, and a number of yellow-flowered *falcata* alfalfa types. After several generations of selfing, crosses have been made between promising lines in an attempt to combine desirable characteristics in one progeny.

Selfing usually results in reduced vigor in alfalfa. The amount of reduction in vigor has varied a great deal among the different lines. Some lines lost vigor very rapidly and were eliminated after one or two years of selfing A few lines have apparently maintained their vigor even after three and four generations of selfing

In connection with studies on winterhardiness, yield of forage, and seed production of these various lines, a study was made also on the inheritance of flower colors. Although the limited amount of material and more or less secondary consideration of this character make definite conclusions impossible, a number of facts have been found that are thought to be worth presenting at this time. Crosses have been made between inbred strains with blue, yellow, and white flowers. The blue- and white-flowered types were of the *sativa* group while the yellow were of the *falcata*.

REVIEW OF LITERATURE

Fryer (2)[3] reports that the haploid number of chromosomes in both *M. sativa* and *M. falcata* is 16. This is an indication that crosses between the species are relatively easy to make and are for the most part fertile.

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[3]Figures in parenthesis refer to "Literature Cited", p. 216.

Waldron (7), endeavoring to explain the inheritance of flower color, found dominance entirely lacking in a cross between *M. sativa* and *M. falcata*. He noted the varied colors in the F_2 generation which prevent division into sharply differentiated groups. Both the ratios found in the F_2 generation and seven subsequent segregating F_3 families admitted the possibility of at least three factors governing color.

Burton (1) states that the marked variability in color of flowers in the F_2 progeny of two hybrids between *M. sativa* and *M. falcata* studied make the explanation of its inheritance on the basis of phenotypic counts impossible. The number of pure yellow-flowered individuals, however, indicate that this character is controlled by three factors.

The approach to the normal made by the distribution curves of all other characters considered suggests that the expression of these characters is governed by a number of genetic factors.

Korohoda (4) found the supposition of two or three hereditary factors determining the coloration of the blossoms in the F_3 generation of the hybrid to be inadequate. His results indicate that, in the given case, at least four factors are involved—one of each fundamental coloration—cream, blue, and violet and one or two factors intensifying these colorations.

Stewart (6) states that the significantly lower variability in the progenies with respect to plant height, plant width, stem diameter, leaflet length and width, blossom color, and foliage color as a result of one generation of inbreeding leaves little doubt that alfalfa is much less heterozygous than it was commonly thought to be. He further reports that blossom color segregated widely, the progenies grading from extremely light violet to extremely dark violet. Many of them were practically pure breeding. Even the variegated varieties yielded nearly uniform blossom color in a high percentage of the progenies.

MATERIAL USED

Eleven inbred lines were used in these crosses. These were obtained from the two variegated alfalfas, Grimm and Cossack, and several varieties of the *falcata* group. They were selfed from one to three generations before being used for crossing purposes. Hansen, a white-flowered alfalfa obtained from Professor N. E. Hansen, of the South Dakota Agricultural Experiment Station, was used in some of the crosses, while in others, selfed strains, S-357 and S-359, from Hansen were used. Hansen breeds true for white flower color.

A detrimental effect of inbreeding was noted in the production of albino seedlings in the progeny of inbred lines. Selfed lines generally showed a reduction in vigor and some were lost. There were some outstanding exceptions.

There were also a few striking cases of hybrid vigor. In one instance in a cross between a *falcata* and *sativa* alfalfa the F_1 plants grew to a height of more than 10 feet in the greenhouse The parents made less than half as much growth (Fig. 1).

TECHNIC USED

Selfing was done by placing a single branch in a muslin-covered circular bag to exclude insects or by placing the entire plant in a wire framework covered with muslin (Fig. 2). The flower clusters were first examined and any tripped members were removed. The hands of the operator were then washed in alcohol to destroy any stray pollen and the flower clusters rolled between the thumb and first finger to cause tripping. The flowers were manipulated every other day, weather per-

mitting, for a month or two. Varied and diversified degrees of ability to set seed were apparent not only in the F_2 generations, but also between the various inbred lines. On the whole, greater numbers of seed were obtained in the greenhouse than in the field.

Two methods were employed for the emasculation of the alfalfa floret. In the field the anthers were removed by directing a jet of water upon them. In the greenhouse both the air suction and the water jet methods were used.

The suction method operates on the principle of the vacuum cleaner. A piece of glass tubing which had been drawn to a fine point over a Bunsen flame, thereby creating a very small opening, was inserted in a rubber tube the other end of which was connected to a small suction pump operated by a small electric motor. When the glass tube was then held over the stamens, the suction efficiently removed the anthers and the pollen.[4]

The water jet method was equally simple. A small jet of water expelled from a hypodermic needle was trained on the anthers of the flower which had been tripped and which was supported on the edge of the thumbnail.

The flower was prepared for emasculation by first cutting off the standard at its point of contact with the wings. Then it was tripped by applying pressure at the base of the keel.

FIG. 1 Hybrid vigor in F_1 generation.

Cross pollination was obtained by applying pollen direct from the stamens of the selected parent plant. Care was exercised to choose well-matured untripped flowers. The anthers from several flowers were applied to the stigma of the emasculated plant to assure pollination. The crossed flower was then covered by a muslin bag supported on a circular frame with a tag attached containing the following data: Female plant, date emasculated, male plant, and the date crossed.

Little success attended the efforts to make crosses in the field. That the water jet method was not responsible for these failures was demonstrated by the fact that both the suction and the jet of water methods were used in making numerous successful crosses in the greenhouse.

Seeds were placed in concentrated sulfuric acid for 8 minutes, washed thoroughly with water, and dried on paper toweling, or nicked with a razor blade in order to secure uniform germination. The seedlings were started in the greenhouse using inoculated soil in either pots or flats. If the seedlings were to be grown for

[4]The authors are indebted to Dr. H. M. Tysdal for suggesting this method.

study in the greenhouse, each plant was transplanted to a 4-inch pot Otherwise they were set out in the field when about 6 inches in height and in the latter part of May During the course of the year the greenhouse plants were sprayed to control frequent infestations of aphids and red spider

Plants were also brought in from the field in the fall to be used for crossing and for obtaining selfed seed during the winter months These were placed in 10-inch pots and 5 grams of a 4–8–8 fertilizing mixture were added to each pot

FIG. 2 — Cage and bags used in crossing alfalfa

Nearly all who have reported work with flower colors in alfalfa have noted the difficulty in making clear cut distinctions between the various colors and in turn their various shades The authors too were faced with this problem Colors on the "Old Faithful Tuned Palet" color chart[5] were used as the basis for classification Each color on the chart was given a number beginning with dark purple as number 1 and ranging to number 20 for white The flower color notes were taken at the standard petal when a number of blossoms were in bloom in each cluster. It was deemed advisable to combine a number of shades into groups in order to facilitate the inheritance studies Eight groups were considered sufficient to cover the different color classifications These were red purple dark purple, light purple,

[5]The "Old Faithful Tuned Palet Color Chart American Crayon Co New York

dark green, light green, yellow-green, yellow, and white. Colors listed in the various tables have been grouped in this manner.

CROSSES INVOLVING PURPLE AND WHITE

Eight crosses were made with inbred Grimm selections as the purple parent and Hansen or selfed progeny of Hansen as the white-flowered parent. In all cases, the F_1 generation had purple flowers indicating a dominance of purple to white. In the F_2 generation these crosses yielded a combined progeny of 411 plants with various shades of purple flowers and 29 white-flowered plants as is shown in Table 1.

TABLE 1 *Segregation of flower color in Medicago crosses involving purple, yellow, and white*

Cross	Number of crosses	F_1 flower color	Distribution of flower color in the F_2				
			Purple	Green	Yellow	White	Total
Purple × white	8	Purple	411			29	440
Purple × yellow	1	Purple	38		10	1	49
White × yellow	1	Purple	23		3	15	41
Var × white	1	Purple	127	140	4	2	273

The numbers of purple and white individuals compared with the calculated numbers for a 15 to 1 ratio are as follows

	Purple	White	Total
Observed	411.0	29.0	440
Calculated (15:1)	412.5	27.5	440

This is a very close fit for these numbers

Seven F_3 progenies were grown. Three of these were from a selfed purple and four were from selfed white-flowered plants Only a few plants were obtained from the purple-flowered plants and these were all of various shades of purple. Thirty plants were produced in the four progenies from the white-flowered F_2 plants. All had white flowers indicating that white flower color breeds true after being isolated.

PURPLE BY YELLOW CROSS

The hybrid X10 resulted from a cross between S201, three generations removed from a purple-flowered Grimm selection, and the yellow-flowered S186 one generation removed from a *falcata* (U. S. 24452).

The F_1 flower color was a light purple indicating, as no apparent dominance was recognized in the F_2, that purple is epistatic to, or covers up the yellow flower color.

A small F_2 progeny of but 49 plants was grown, 38 of which were classified as purple and 10 as yellow. One white-flowered individual was found (Table 1).

Considerable difficulty was experienced in classifying these F_2 progenies as about 20% of the plants possessed variegated flowers which changed from purple through green to yellow. Moe (5),

Hagem (3), and Burton (1) also report that this condition caused difficulty in classification. Variegated flowers were apparent in neither parents nor F_1.

Though the F_2 progeny was small and was hardly large enough to warrant that any conclusions with respect to color inheritance be drawn, the wide range of color and the relative numbers of purple, yellow, and white-flowered plants indicated that at least a three-factor difference was responsible.

When the observed numbers are compared with the calculated assuming a three-factor difference with purple epistatic to yellow the following results are obtained:

	Purple	Yellow	White	Total
Observed.	38	10	1	49
Calculated (12:3:1). .	37	9	3	49
Difference	1	1	2	0

The closeness of this fit suggests that the theory applied is a logical one. None of the yellow plants obtained were identical with the pure yellow of the *falcata* parent. The failure of the pure yellow to appear is assumed to be due to various modifying factors

Three F_3 progenies were grown One of these bred true for white while the other two from purple-flowered parents bred true for this color.

WHITE BY YELLOW CROSS

The hybrid X35 resulting from a cross between S359 and S360, the latter a yellow-flowered *falcata* alfalfa one generation removed from U. S. 35312, proved to be of interest as it was a light purple-flowered plant. The occurrence of this purple-flowered F_1 initiated the assumption that a factor for purple color may be carried in the white-flowered parent plant in the presence of the recessive condition of a factor for the production of color.

An F_2 progeny of 41 plants was classified into three groups as regards color. As is shown in Table 1 these were yellow, light purple, and white. The large number of white-flowered individuals in this comparatively small F_2 progeny allows for the assumption of the presence of another dominant factor for the production of color which is supplementary to the first.

The F_2 phenotypic ratio admits the possibility of a three-factor ratio as is evidenced by the following comparison of observed to calculated numbers:

	Purple	White	Yellow	Total
Observed .	23	15	3	41
Calculated (36:19:9). .	23	12	6	41
Difference. . . .	0	3	3	0

Here again the observed compares favorably with the calculated results. F_3 progeny were not grown as selfed F_2 plants failed to set seed.

CROSSES RESULTING IN VARIEGATED FLOWER COLOR

X25 was the result of a cross between Hansen and S206 which was three generations removed from a Cossack selection. Cossack is a variegated alfalfa. The F_1 of this cross showed a very interesting condition as regards flower color. Each floret was dark purple upon blooming, but in the course of a day or two changed to dark green; consequently, there resulted inflorescenses which contained both purple and green flowers.

An F_2 progeny of 273 plants was grown which ranged in flower color from purple through green and near yellow to white (Table 1). It is interesting to note that nearly a third of these plants were of variegated color. This seems to indicate the presence of a single recessive factor for variegated flowers However, the F_1 showed variegated flowers and appears to have reverted to the characteristic variegated alfalfa from which its purple parent arose. The F_3 progenies further indicate more than a single recessive factor since both solid and variegated flowering plants segregated for this condition.

To facilitate classification, flower color was taken after the color had changed.

The wide color range and the large number of colored plants in proportion to the white suggests the presence of at least four factors.

As is shown in Table 2, seven F_3 families segregated for color, but the variation was not so wide as in the F_2 generation, except where a variegated F_2 plant was the parent. This narrowing of the range of variation suggests that some of the plants already tended towards homozygosity and also that variegated plants were in a heterozygous condition for more factors.

TABLE 2.—*Segregation for flower color in F_3 generation families of the cross F_1 25.*

F_3	Color of F_2	Distribution for color in F_3								
		Red-purple	Dark purple	Light purple	Dark green	Light green	Yellow-green	Yellow	White	Total plants
F_3 25-1	Yellow-green	-	-	7			1		-	8
F_3 25-2	Light purple	—	1	9	—	-	3		4	17
F_3 25-3	Yellow-green	—	1	6	-	—	3	4	3	17
F_3 25-4	Yellow-green	—	2	7		1	3	-	1	14
F_3-25-5	Light purple	—	-	3	—	-	-	-	—	3
F_3 25-6	Light green	—	2	7			6	4	2	21
F_3-25-7	Dark purple and dark green	-	1	8	6	1	6	1		23

INTERACTION OF FLOWER COLORS

It has been suggested that there appear to be present two dominant supplementary factors which influence the production of color. The absence of both of these factors results in white flowers whether or not

the individual plant carries factors for color. Purple was regarded as epistatic to yellow.

Employing these explanations and letting P represent the factor for purple, Y the factor for yellow, and C and A the supplementary factors for the production of color, the following genetic makeup of the various types was assumed:

Purple	PPCCAAyy
Yellow	ppCCaaYY
White	PPccaayy

On this basis a 15 to 1 ratio of purple to white would be obtained in purple and white crosses; a 12 to 3 to 1 purple-yellow-white ratio in purple by yellow crosses; and a 36 to 9 to 19 Purple-yellow-white ratio in the yellow by white crosses.

Although the numbers are not large and not enough F_3 progenies have been studied to substantiate this hypothesis, the authors would like to present it as a tentative basis for the explanation of the results obtained in these crosses.

LITERATURE CITED

1. BURTON, G. W. The inheritance of various morphological characters in alfalfa and their relation to plant yields in New Jersey. N. J. Agr. Exp. Sta. Bul. 628. 1937.
2. FRYER, J. R. Cytological studies in Medicago, Melilotus, and Trigonella. Can. Jour. Res., 3:3–50. 1930.
3. HAGEM, O. Some F_2 and F_3 generations of the hybrid *Medicago sativa* and *Medicago falcata*. Hyt Mag. Naturvidenskab., 56:149–165. 1919. (Review in Bot. Abst., 8:222. 1920.)
4. KOROHODA, J. Inheritance of certain characters of the hybrid of *Medicago sativa* and *Medicago falcata*. Pam. Panst. Inst. Nauk. Gosp. Wiejsk. Pulawach. 1933. (Mem. Inst. Natl. Polon. Econ. Rurale Pulawy, 14:378–393.) In Polish with English summary. Seen in abstract.
5. MOE, G. G. Alfalfa studies: A preliminary study of the inheritance of certain morphological characters. Unpublished thesis, Cornell Univ. 1928.
6. STEWART, G. Effects of inbreeding on variability in alfalfa. Jour. Agr. Res., 49:669–694. 1934.
7. WALDRON, L. R. Vererbung der Blutenfarbe bei Hybriden von Medicago sativa und M. falcata. Pflanzenbau, 6:157–166. 1929.

SOME CHANGES IN THE SOIL DURING NATURAL SUCCESSION OF VEGETATION AFTER ABANDONMENT IN WESTERN NEBRASKA[1]

B. Ira Judd and M. D. Weldon[2]

THE investigations reported here were part of a study of the natural succession of vegetation on abandoned farm lands in Kimball County, Nebraska. The study was confined to the Rosebud soils, which have been described by Jackson, Hayes, and Weldon (3).[3] Its purpose was to determine some of the changes occurring in the soil during the process of revegetation. Native grassland areas, cultivated fields, and fields abandoned for different periods of time were used. The rate of infiltration of water was observed in the field. The volume-weight, rate of percolation of water, state of aggregation, and organic matter, nitrogen, and root content were investigated in the laboratory.

RATE OF WATER INFILTRATION AND VOLUME-WEIGHT

Areas abandoned 1, 3, and 7 years were used for this study, together with adjacent native grassland and cultivated fields for comparison. In each abandoned area four conditions of vegetation were studied, *viz.*, (a) spots in which the dominant species were grasses, (b) spots in which the dominant species were forbs,[4] (c) spots having a mixed grass and forb vegetation, and (d) bare areas. Where grasses were dominant, the principal species were *Setaria viridis* on land abandoned 1 year and *Bromus tectorum* on land abandoned 3 years. Where forbs were dominant, the principal species were *Salsola pestifer* on 1-year abandonment and *Plantago purshii* on the 3-year abandonment. In the areas of 7-year abandonment, *Agropyron smithii* and *Chenopodium album* were dominant species in the grass and forb areas, respectively.

PROCEDURE

Two cylindrical tubes of brass, 3.867 inches in inside diameter, 6 inches long, and having a wall thickness of 0.0625 inch, were fastened end to end by means of a ½-inch strip of tinned sheet iron encircling the joint and soldered on. One cylinder had a cutting edge which facilitated its entrance into the soil. This composite tube was forced into the soil until the top of the upper cylinder was even with the

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[2]Head, Dept. of Agriculture, Teachers College, Tempe, Arizona, and Associate Professor of Agronomy, University of Nebraska, respectively. Acknowledgments for helpful suggestions are made to J. C. Russel, Professor of Agronomy, University of Nebraska, and Special Agent, Soil Conservation Service; and to M. L. Jackson, formerly undergraduate assistant in the field.

[3]Numbers in parenthesis refer to "Literature Cited", p. 227.

[4]The term *forb* refers to any non-grasslike herb.

surface.[5] After the removal of some of the soil around the outside, a rubber extension (a band of automobile tire inner tube 3.5 inches in diameter and 2 inches wide) was attached to the brass cylinder, leaving about 1 inch of rubber projecting above the brass to act as a reservoir to hold water.

The first 100 cc of water was added only as rapidly as it would disappear in order to maintain the hydrostatic head at a minimum. Thereafter, the water was added in 100-cc portions, making an initial depth of 1.3 cm above the soil surface. As soon as one addition of water had been absorbed by the soil, the next was added immediately. The exact time required for each 100-cc portion to disappear was recorded until 800 cc, equivalent to approximately 4 inches of water, had been added to each cylinder. After the last portion had disappeared, the rubber band was removed and the cylinder was covered with a close-fitting brass lid. The whole was covered with debris to protect the soil from insolation and loss of moisture.

A period of 72 hours was allowed for excess moisture to drain away. Each cylinder was then excavated, and the lower end of the soil column was cut off flush with the end of the cylinder. The strip of tin-plate was removed by winding it off with a key, and the column of soil was cut in two at the joint between the two 6-inch cylinders by means of a fine wire. The contents of the two cylinders were placed in separate paper bags and set aside to dry. The samples were later used in the determination of volume-weight and root content.

Quadruplicate determinations were made in each area.[6] The results shown in Figs. 1 to 3 represent the average of the four replications. The rate of intake of water was at first very rapid, but became slower after the absorption of 100 to 200 cc (0.5 to 1.0 inch), and remained fairly constant thereafter. There was some tendency for the rate of movement of water to increase after 400 to 600 cc (2 to 3 inches) had been added. This is undoubtedly the result of the lateral spread of water after it reached the unconfined lower end of the 12-inch column.

OBSERVATIONS

VOLUME-WEIGHT

Table 1 shows the volume-weight of the soil samples from the first and second 6-inch depths of the various areas, and the rates of infiltration of water through the 12-inch column. In general, there appears to be a negative correlation between the volume-weight of the surface 6 inches of soil and the infiltration rate. The 7-year abandonment condition has a low volume-weight and a high infiltration rate, while the 1-year abandonment has a high volume-weight and a

[5]For the purpose of forcing the cylinder down, two augers were set into the soil 30 inches apart A wooden span was placed between these and rested against collars held on the auger stems by set screws The cylinder was placed, sharp edge downward, midway between the two augers and an automobile jack was set on the top of the cylinder with the top of the jack against the wooden span. The cylinder was then forced down by means of the jack. This method was developed by J. C. Russel, Associate Professor, and Boris Bulatkin, formerly Graduate Assistant, of the Department of Agronomy, University of Nebraska. It leaves the soil in the cylinders undisturbed and permits tests that are comparable to natural conditions.

[6]Russel and Bulatkin recommended 10 or more replications to minimize the errors resulting from cracks, root-channels, textural variability, etc. Time did not permit the taking of such a number of replications, and the results obtained may not be entirely representative.

low infiltration rate. The volume-weights of the 6- to 12-inch samples are comparatively uniform and are apparently not related to the infiltration rate. Water was absorbed by the soil of the stubble fields much more rapidly than by the more compact, less porous soil of the native grassland. The stubble field used for comparison to the 7-year abandoned land which had been severely eroded by wind thus exposing the more compact subsoil proved an exception. It has frequently been observed that the absorption of water is much slower where such conditions occur as the result of erosion.

TABLE 1. *Volume weights and infiltration rates of the soils under wheat stubble, native grasses, and three different periods of abandonment*

Area	Volume weight grams per cc		Time required for absorption of 800 cc of water, minutes	Average infiltration rate inches per hour
	0-6 in	6-12 in		
Wheat stubble	1.11	1.23	83	2.98
Native grassland	1.23	1.31	184	1.34
Abandoned 1 year				
Grasses dominant	1.24	1.38	140	1.78
Forbs dominant	1.30	1.34	726	0.34
Mixed vegetation	1.23	1.37	278	0.89
Bare	1.25	1.35	315	0.79
Average	1.26	1.36	365	0.68
Wheat stubble	1.19	1.40	55	4.48
Native grassland	1.29	1.40	176	1.41
Abandoned 3 years				
Grasses dominant	1.18	1.32	61	4.05
Forbs dominant	1.26	1.37	136	1.83
Mixed vegetation	1.22	1.35	61	4.05
Bare	1.31	1.36	118	2.10
Average	1.24	1.35	94	2.64
Wheat stubble	1.21	1.37	216	1.15
Native grassland	1.08	1.35	102	2.45
Abandoned 7 years				
Grasses dominant	1.18	1.38	117	2.12
Forbs dominant	1.06	1.37	65	3.82
Mixed vegetation	1.10	1.35	55	4.51
Bare	1.24	1.38	102	2.42
Average	1.14	1.37	85	2.92

PERCOLATION RATE

When the field work on infiltration of water was completed, the 6-inch brass tubes were coated inside with paraffin and put down in the same 3-year abandoned area as that used for the infiltration study. Triplicate samples were taken from each of the six surface conditions. About 400 cc of water were added, and the cylinders full of moist soil were excavated 2 days later. The soil column was cut off even with the bottom of the cylinder and lids were placed on each end of the cylinder and taped securely to prevent evaporation. In this

manner the soil was kept in an undisturbed field-moist condition until the percolation study could be undertaken.

The procedure used for obtaining percolation rate was as follows: The lids were removed from the ends of the brass cylinder and the bottom of the soil column was covered by filter paper, cheesecloth, and galvanized hardware cloth, successively. The cylinder was placed upright in a funnel which supported the hardware cloth in proper position. On top of the soil column were placed a filter paper and a disc of brass window-screen wire to prevent erosion of the soil when water was added. A band of rubber inner tube was placed around the top of the cylinder, the same as for the infiltration experiment. Six funnels and cylinders were supported in a rack. Fastened to the top of the rack were two small iron pipes. One of these was attached to a vacuum pump and the other to a supply of water. By means of rubber connections and screw clamps, both inflow of water and suction could be regulated as desired The apparatus maintained a thin sheet of water on the surface of the soil and thus maintained a small constant hydrostatic head.

Graduated cylinders were placed under the funnels to catch the percolate. After the first 50 cc had been discarded, the volume of percolate was recorded each hour for 6 hours The results are shown graphically in Fig. 4 as averages for the three cylinders from each vegetative condition.

There appears to be a slight negative correlation between the percolation rates and the volume-weights of the soils (Table 1). The native grassland and bare areas, with high volume-weights, permitted the slowest percolation; the mixed vegetation and annual grass areas showed medium to low volume-weights and intermediate percolation rates; and the wheat stubble area, having a low volume-weight, permitted rapid percolation. The forb area, however, had a relatively high volume-weight and also a high percolation rate. The conclusion may be drawn from these facts that the percolation rate is not directly related to the total pore space of the soil but depends also on the size and character of the pores, as suggested by Krause (4). Large continuous cracks and channels permit more rapid percolation, while the small, capillary pore spaces of the native grass and bare areas cause a much slower movement of water.

AGGREGATE ANALYSIS

After the percolation experiments were completed, the soil in the cylinders was used for a study of the state of aggregation. The cylinders of wet soil were placed in contact with dry soil for 24 hours to draw off the excess water by capillary action. The moist soil was then removed from the brass cylinders and screened through a sieve of four meshes per inch. This was done carefully in order to disturb the aggregates as little as possible. After the soil had been thoroughly mixed the percentage of the soil mass present in the form of aggregates larger than 0.5 mm in diameter was determined by the method of Tiulin (8), as described by Rhoades (5). The results, which are the average of determinations on the three cylinders of soil from each vegetative condition, are presented in Table 2.

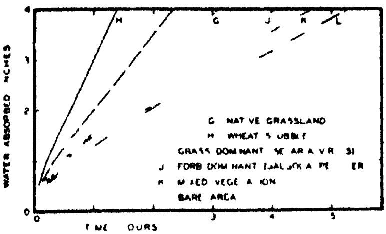

FIG. 1 Rate of infiltration of water into soil under native grassland vegetation under wheat stubble and under different vegetative cover after 1 year of abandonment

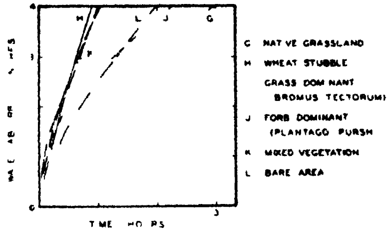

FIG. 2 Rate of infiltration of water into soil under native grassland vegetation under wheat stubble, and under different vegetative covers after 3 years of abandonment

TABLE 2 *State of aggregation volume weight infiltration rate and percolation rate of soils under native grasses wheat stubble and different kinds of vegetative cover after 3 years of abandonment*

Area	Aggregates larger than 0.5 mm %	Volume weight	Infiltration rate inches per hour	Percolation rate inches per hour
Grass dominant	16.3	1.18	4.05	0.43
Wheat stubble	18.8	1.19	4.48	0.84
Forb dominant	21.0	1.26	1.83	0.97
Mixed vegetation	25.4	[illegible]	4.05	0.49
Native grasses	30.6	1.29	1.41	0.11
Bare area	31.3	1.31	2.10	0.20

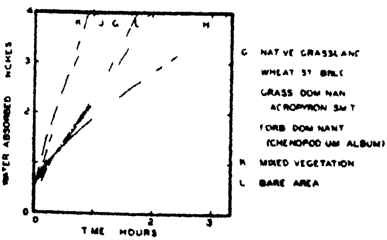

FIG. 3 Rate of infiltration of water into soil under native vegetation under wheat stubble and under different vegetative covers after 7 years of abandonment

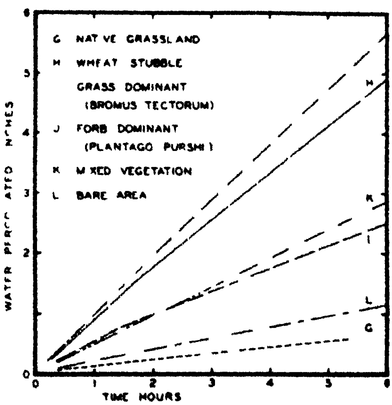

FIG. 4 Rate of percolation of water through soils from areas under native grasses wheat stubble and different vegetative covers after 3 years of abandonment

The native grassland soil and that from the bare area showed a high degree of aggregation, about 31% of the entire soil existing in the form of aggregates larger than 0.5 mm in diameter. Under the other conditions, the degree of aggregation was lower.

In Table 2 the figures on aggregate analysis are arranged in the order of increasing magnitude to show more clearly the correlation between this characteristic and the volume-weight, the rate of infiltration of water in the field, and the laboratory percolation rate. It is evident from the table that there is a greater proportion of large aggregates in the more compact soils and that water moves through such soils more slowly In the soils that have been loosened by cultivation, water moves more rapidly, but many of the aggregates have been reduced to 0 5 mm or less in size

ROOT CONTENT

The soil samples on which infiltration rate and volume-weight determinations were made were used for making comparisons of the root content of native grassland, wheat stubble, and the different periods of abandonment They were soaked in water for a few hours and then separated from the root material by means of a battery of grain-grading sieves. The finest sieve had openings 2 mm in diameter. The soil was placed upon the coarsest sieve and a jet of water played upon it until only the gravel and root material were left. This process was repeated for each sieve. The combined residues were then washed into a pan of water. The roots were separated from the gravel, oven-dried, and weighed The average amount of root material in four cylinders for each condition studied is given in Table 3. Since each cylinder had an average inside diameter of 3.867 inches, and a corresponding cross-sectional area of 11.75 square inches, it was possible by means of these data to compute the approximate weight of roots per acre under each of the conditions studied. The results of these calculations also are shown in Table 3. In the final column, the relative root content of each area is expressed on the basis of the corresponding native grassland area as 100 For the 1-year and 3-year periods of abandonment, there is no great difference between the abandoned fields and the stubble fields, all of them having about one-fourth to one-third of the root content of the corresponding areas of native grass After 7 years of abandonment, the root content had increased to nearly half that of the native grassland. The stubble land corresponding to the 7-year abandoned area is not comparable, however, because wind erosion had removed much of the surface soil. The data indicate that the quantity of root material in the soil under cultivation is much less than under native vegetation, and in the course of several years of abandonment an appreciable increase occurs.

ORGANIC MATTER AND NITROGEN

Composite samples of 10 cores of soil were taken from areas of different periods of abandonment, cultivated land, and native grassland for the determination of organic matter and nitrogen content. These were taken at random and are meant to be representative of average conditions in each area. A tube 2 inches in diameter was used for the 0- to 6-inch depth and a 1-inch tube for the 6- to 12-inch depth.

TABLE 3.—*Weight of root material in the soil of native grassland, wheat stubble, and abandoned areas.*

Area	Roots in four cylinders, grams		Root material per acre, lbs.			Relative root content, native as 100
	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–12 in.	
Native grassland...	12.81	2.56	3,770	753	4,523	100
Wheat stubble.....	3.25	0.20	956	59	1,015	22
Abandoned 1 year:						
Grasses dominant	3.23	0.34	951	100	1,051	
Forbs dominant..	3.16	0.39	930	115	1,045	
Mixed vegetation	4.90	0.40	1,442	118	1,560	
Bare............	3.48	0.13	1,024	38	1,062	
Average.......	——	——	1,087	93	1,180	26
Native grassland...	11.59	1.94	3,411	571	3,982	100
Wheat stubble.....	3.88	0.54	1,142	159	1,301	33
Abandoned 3 years:						
Grasses dominant	4.87	0.32	1,433	94	1,527	
Forbs dominant..	2.75	0.90	809	265	1,074	
Mixed vegetation	3.80	0.48	118	141	1,259	
Bare..........	1.18	0.34	347	100	447	
Average.......	——	——	927	150	1,077	27
Native grassland...	9.90	1.44	2,914	424	3,338	100
Wheat stubble.....	0.46	0.08	135	24	159	5*
Abandoned 7 years:						
Grasses dominant	5.71	1.23	1,680	362	2,042	
Forbs dominant..	5.36	0.31	1,577	91	1,668	
Mixed vegetation	6.33	0.20	1,863	59	1,922	
Bare	2.20	0.14	647	41	688	
Average.......	——	——	1,442	138	1,580	47

*This field had been severely eroded by wind.

The composite samples were dried and screened through a sieve of four meshes per inch. All roots and rhizomes were cut and mixed with the soil without loss. After each sample had been thoroughly mixed, a pint of sub-sample was removed and ground to pass through a 0.5-mm sieve.

Nitrogen was determined by the usual Gunning method (2). Organic matter was determined by a modification[7] of the hydrogen

[7]The Robinson method, as modified by Prof. J. C. Russel, Department of Agronomy, University of Nebraska, is as follows: Arrange a series of uniform 50-cc glass-stoppered weighing bottles in pairs of nearly equal weight. Number them consecutively, giving the lighter one of each pair the odd number. Clean and dry the weighing bottles, remove the stoppers, and allow them to come to hygroscopic equilibrium with the atmosphere. Weigh out on a counterpoised scoop two 2.000-gram portions of air-dry soil (1.000 gram in case of soils containing much over 5% of organic matter, and 0.2000 gram in the case of peat or organic materials), and transfer to two paired weighing bottles. Stopper the bottles as filled. When all samples are weighed out, place the bottles in pairs on the balance, the odd-numbered bottle (the lighter) on the right pan, and the other on the left, and determine to the fourth decimal the difference in their weights. Set the even-numbered bottle aside for the time. Transfer the contents of the odd-numbered bottles to beakers, using a little water to rinse out traces of soil, then set these

peroxide method of Robinson (6). Most of the duplicate samples agreed within 0.001 gram and in cases of differences greater than 0.002 gram new determinations were made. Russel and Engle (7) have shown that the method is reliable and yields results which agree well with those obtained by multiplying the organic carbon content by the conventional factor 1.724. The hygroscopic coefficient was determined by the method of Alway, Kline, and McDole (1).

The results of the organic matter and nitrogen determinations are presented in Table 4. There is such great variation that no definite conclusions can be drawn as to the changes in soil organic matter and nitrogen resulting from cultivation and abandonment. The data appear to indicate a loss of these constituents from the upper 6 inches of soil under cultivation, but statistical analysis shows that the differences are not significant. In the 6- to 12-inch depth the average figures for organic matter and nitrogen are practically identical in native grassland, wheat stubble, and abandoned areas.

By means of the data on volume-weight, total organic matter content, and root content, from Tables 1, 3, and 4, the percentage of root material in the whole mass of soil organic matter may be computed. The results of such computations are shown in Table 5.[8]

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bottles aside. Now add 10 cc of 30% hydrogen peroxide to each beaker, cover with a glass, and digest on a carefully regulated hot plate. From time to time the beakers should be rotated to rinse down the sides. After all of the peroxide has been decomposed, remove the beaker from the hot plate, and if necessary, add 5 cc more of peroxide, rinsing the sides of the beaker with it. Continue the digestion until all of the peroxide is decomposed. 15 cc of hydrogen peroxide used in this way is usually sufficient for all soils, but if incomplete digestion is feared, more should be used. After digestion is complete, scrub the cover glass well with a policeman and rinse into the beaker. Transfer the contents of the beakers to 100 cc centrifuging tubes into which 5 cc of 10% ammonium carbonate solution has previously been placed Scrub the beakers well with a policeman. The rinsings should not exceed 80 to 90 cc and the tube should finally be filled with a strong jet of water that will mix the contents thoroughly. Cover the beakers and set aside. Allow the tubes to set for a time for flocculation to occur, and then centrifuge until the supernatant liquid is very clear. Pour off the liquid into the original beaker in which the soil was digested and set aside. Agitate the residue with a little water, then rinse it into its original weighing bottle and scrub the tube thoroly with a policeman. With experience and care, the tube can be completely washed without more than once filling the weighing bottle. Place the bottle and lid in the oven and evaporate to dryness, then place beside it the companion bottle containing the moisture sample and continue drying at 110° for at least 8 hours. Cool the weighing bottles in pairs in the same desiccator, and re determine the difference in their weights. Remove the odd-numbered weighing bottle and weigh the other bottle and contents to the third decimal. Subtract the weight of the bottle to obtain the oven-dry weight of the sample used. Ignite, cool in a desiccator, and weigh to the fourth decimal a series of platinum dishes. Transfer the contents of the beakers to the dishes and evaporate to dryness, then ignite in a medium red muffle furnace for a few minutes, cool in a desiccator, and weigh. Calculate the weight of the ignited residue. To calculate organic matter content, subtract the initial difference from the final difference in weigh-bottle weights, and subtract from this the weight of the ignited residue in the dish. This gives the weight of organic matter in the sample. Divide this weight by the oven-dry sample weight and multiply by 100 to obtain the percentage of organic matter.

[8]The volume-weights of the native grassland and wheat stubble soils are the averages for the three fields of Table 1 and those of the abandoned soils are the average of the four different surface conditions for each period of abandonment. The organic matter percentages are from Table 4, and the weights of root material per acre are from Table 3, the figures for the three native grassland areas were

TABLE 4.—*Soil organic matter, nitrogen, and organic matter-nitrogen ratios in areas of native grass, wheat stubble, and abandoned land.*

Area	Organic matter, %		Nitrogen, %		OM/N ratio	
	0–6 in.	6–12 in.	0–6 in.	6–12 in.	0–6 in.	6–12 in.
Native grassland.....	2.42	0.64	0.149	0.098	16.2	6.5
	4.10	2.32	0.224	0.150	18.3	15.5
	3.15	1.04	0.198	0.115	15.9	9.0
	2.91	1.36	0.152	0.098	19.1	13.9
	1.56	1.75	0.097	0.068	16.1	25.7
Average........	2.83	1.42	0.164	0.106	17.3	13.4
Wheat stubble.......	3.13	0.84	0.199	0.067	15.7	12.5
	3.07	1.47	0.204	0.145	15.0	10.1
	1.75	1.04	0.116	0.097	15.1	10.7
	1.80	1.44	0.112	0.093	16.1	15.5
	3.24	1.66	0.078	0.078	41.5	21.3
	1.85	1.70	0.127	0.141	14.6	12.1
Average........	2.47	1.36	0.139	0.107	17.8	12.7
Abandoned 1 year....	2.76	1.75	0.175	0.133	15.8	13.2
	2.03	1.52	0.153	0.095	13.3	16.0
Average..........	2.40	1.64	0.164	0.114	14.6	14.4
Abandoned 2 years...	2.00	1.50	0.116	0.104	17.2	14.4
Abandoned 3 years...	2.45	1.63	0.150	0.093	16.3	17.5
Abandoned 4 years...	2.27	0.86	0.132	0.105	17.2	8.2
	1.56	1.26	0.095	0.079	16.1	15.9
Average..........	1.92	1.06	0.114	0.092	16.8	11.5
Abandoned 5 years...	3.11	1.06	0.168	0.106	18.5	10.0
Abandoned 6 years...	2.06	1.08	0.128	0.108	16.1	10.0
Abandoned 7 years...	2.83	1.63	0.170	0.112	16.6	14.6

Under native grassland vegetation 7.3% of the "soil organic matter" in the surface soil and 2.2% of that in the second 6 inches was found to consist of root material. These figures compare favorably with those of Weaver, Hougen, and Weldon (9), who found that in the surface 6 inches 8.5 to 10.6%, and in the second 6 inches from 2.8 to 3.8% of the "soil organic matter" consisted of plant roots and rhizomes in native grassland meadows at Lincoln and Union in eastern Nebraska. The cultivated and abandoned lands, however, had a much lower percentage of root material in the soil organic matter. This may be considered as evidence of the incorporation into the soil mass of a much smaller amount of root material than under the native grasses.

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averaged, but those for the wheat stubble area for comparison with the 7-year abandonment were omitted because of wind erosion in this field, and the other two fields of wheat stubble were averaged. As in case of the volume-weights, the figures for each period of abandonment were the average for the four vegetation conditions.

TABLE 5.—*Relationship between root material and soil organic matter in the soil of native grassland and wheat stubble areas and of fields abandoned for 1, 3, and 7 years.*

Area	Volume-weight		Weight of soil, thousands of lbs. per acre		Organic matter, %		Organic matter, lbs per acre			Root material, lbs. per acre			Root material in soil organic matter, %		
	0–6 in	0–12 in.	0–6 in.	6–12 in	0–6 in.	6–12 in	0–6 in	6–12 in	0–12 in	0–6 in	6–12 in	0–12 in	0–6 in	6–12 in.	0–12 in
Native grassland	1.20	1.35	1,631	1,835	2.83	1.42	46,160	26,060	72,220	3,365	583	3,948	7.29	2.24	5.47
Wheat stubble	1.17	1.33	1,590	1,808	2.47	1.36	39,270	24,590	63,860	1,049	109	1,158	2.67	0.44	1.81
Abandoned 1 year	1.26	1.36	1,712	1,848	2.76	1.75	47,250	30,120	77,370	1,087	93	1,180	2.30	0.31	1.53
Abandoned 3 years	1.24	1.35	1,685	1,835	2.45	1.63	41,280	29,910	71,190	927	150	1,077	2.25	0.50	1.51
Abandoned 7 years	1.14	1.37	1,549	1,862	2.83	1.63	43,840	30,350	74,190	1,442	138	1,580	3.29	0.45	2.13

Calculation of the ratios of organic matter to nitrogen in the surface soils of the native grass, wheat stubble, and abandoned areas, and of the standard errors of the mean ratios of the three groups of samples, failed to indicate significant changes in the organic matter-nitrogen ratio of the soil in either the first or second 6-inch depth as a result of cultivation or abandonment. If changes have occurred, a larger number of samples from each area would be needed to reveal them.

SUMMARY

A study was undertaken on cultivated land, native grass land, and land abandoned for various periods of time in Kimball County, Nebraska, for the purpose of discovering the changes that occur in the soil during the process of revegetation. Determinations were made of the rate of infiltration of water in the field and of percolation in the laboratory, the volume-weight, the state of aggregation, and the quantity of plant roots, organic matter, and nitrogen in the soil.

The rate of infiltration of water in the field was considerably greater under wheat stubble than under native vegetation. It was relatively low after 1 year of abandonment, but after several years became approximately equal to that of the wheat stubble land. Bare areas in the abandoned land generally had a low infiltration rate.

The rate of percolation of water through a 6-inch column of topsoil showed about the same relationships as the infiltration rate. Percolation in the soil from the native grassland and the bare areas of the abandoned land was much slower than in that from the stubble field and the abandoned areas under vegetative cover.

The volume-weight and the state of aggregation of the soils were very closely correlated. The volume-weight and the percentage of large aggregates (larger than 0.5 mm) were highest in the soils having the lowest infiltration and percolation rates and were generally lowest in the soils permitting the fastest infiltration and percolation.

The root content of the soil of the cultivated fields, determined shortly after wheat harvest, was found to be one-fourth to one-third of that under native grassland vegetation. After several years of abandonment, the root content of the soil was greater than in cultivated fields and was approximately half of that under native grasses.

The organic matter and nitrogen content of the soil of cultivated and abandoned fields tended to be lower than in the native grasslands, but the difference was not statistically significant for the number of samples taken.

Under the native grasses 7.3% of the soil organic matter in the surface 6 inches and 2.2% of that in the second 6 inches was found to consist of plant roots. Under cultivation or abandonment, the percentage of root material was much smaller.

LITERATURE CITED

1. ALWAY, F. J., KLINE, M. A., and McDOLE, G. R. Some notes on the direct determination of the hygroscopic coefficient. Jour. Agr. Res., 11:147-166. 1917.
2. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and tentative methods of analysis. Ed. 4. 1935. (Page 5.)

3 JACKSON M L HAYES F A and WELDON, M D Some chemical and morphological relationships between soil profiles of the Rosebud and associated soil series in southeastern Kimball County Nebraska Soil Sci Soc Amer Proc 2 437 445 1937
4 KRAUSE M Russian investigations in the field of soil structure Landw Jahrb 73 603 690 1931
5 RHOADES H F Aggregate analysis as an aid in soil structure studies Amer Soil Survey Assoc Bul 13 165 169 1932
6 ROBINSON W O The determination of organic matter in soils by means of hydrogen peroxide Jour Agr Res 34 339 356 1927
7 RUSSEL J C and ENGLE E B The organic matter content and color of soils in the central grassland states Proc 1st Intern Cong Soil Sci, Com V, 4 343 349 1927
8 TIULIN A TH Some questions on soil structure II Aggregate analysis as a means of determining the true soil structure Proc Intern Soc Soil Sci 4 51 54 1929
9 WEAVER J E, HOUGEN V H and WELDON M D Relation of root distribution to organic matter in prairie soil Bot Gaz 96 389 420 1935

TOWARD A GRASSLAND AGRICULTURE[1]

P. V. Cardon[2]

DESTRUCTION of grass[3] has so long characterized land use in America, and the movement to restore grass is so recent, that it would be erroneous to state unqualifiedly that this country is adopting a grassland agriculture. It may never be practicable for America to adopt generally the grassland practices of Europe or New Zealand; and there is reason to question the economic feasibility of adopting such practices in certain parts of this country. But that America during the last few years has launched and is supporting movements tending definitely in the direction of a grassland agriculture is plain to every observer. The more I learn of the historical development of grassland agriculture the more I am disposed to feel that America is treading the same course as that followed by other countries a generation or more ago.

America today is definitely grass-minded. But America still lacks the profound grass consciousness which prompts Europeans to take advantage of favorable physical conditions, to grow more and better grass, and to utilize it to better advantage.

Grass-consciousness differs from grass-mindedness. The one may be and probably is an outgrowth of the other, but grass-consciousness is the more profound. Grass-mindedness inspires grass culture for specific purposes, as, for example, a corrective of soil erosion. Grass-consciousness, on the other hand, regards such specific uses of grass as incidental to its primary uses. It is grass *itself* that is important--grass as a farm crop which is worthy of as good land and as intelligent culture as any other crop. Grass is a crop around which to build profitable farm enterprises, it conserves the land, it benefits other crops grown in rotation with it; it is the basis of a type of farming in which the control of erosion, the protection of water-sheds and the improvement of pastures and ranges follow as matters of course. Thus, grass-consciousness recognizes and utilizes the intrinsic, greater value of grass without discounting but automatically providing for the full play of its incidental values. The culture of other crops fits into this grassland background and grassland agriculture emerges.

It is because America has not yet come fully to appreciate grass as a crop worthy of intensive cultivation and thoughtful management, that she must be regarded as only grass-minded. Speaking broadly, she still thinks of pastures as primarily suited only to that land deemed too poor for other crops; she still thinks of pasture improvement as related only to that land now in pasture, with little regard to the possibility of having better pastures on better land, where

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[3]As used in this paper the term "grass" is inclusive of the true grasses and of the legumes usually found in meadows and pastures.

they might prove as profitable as most other crops; she still thinks of grazing as merely a process of turning the livestock "out to grass"; she still regards grass as a tool to be used in erosion control instead of regarding erosion control as a resultant of grass establishment and utilization for the value of the grass itself. True, here and there over the country, one finds exceptions to this rule, but they are exceptions.

But America's topsy-turvy thinking with respect to grass is, I believe, becoming a thing of the past. Having come to an appreciation of grass as a valuable resource, we are turning to methods of restoring grass on lands from which we earlier mistakenly ripped the sod. We sense now the value of grass in protecting us from the ravages of drought, wind and flood; as a substitute crop on acres contributing to surpluses of corn, wheat, and cotton; and as a soil-building crop to replace soil-depleting crops. Moreover, we are experiencing in our efforts to restore grass serious difficulties which tend to make us all the more appreciative of grass cover once it is restored. By this route we shall pass in time from grass-mindedness into grass-consciousness.

This is a significant trend, likely to contribute notably toward a solution of current agricultural problems, but capable at the same time of creating new problems possibly as stubborn as some with which we now contend. That more and better grass has a place in American agriculture, I have no doubt. But whatever that place it will be determined in the long run by the extent to which it fits into economic farm practice. Grass culture induced by subsidy, under any program of soil conservation, may prove helpful in meeting emergency situations; but grass culture, to be most helpful to American agriculture through the long years ahead, must be induced by an inner grass-consciousness on the part of farmers themselves.

That is the long-view on grass. In holding it, I intend no undervaluation of current programs, each of which is exerting an influence conducive to wider use of grass in America. But I, for one, feel that all such programs would contribute even more if carried out according to a pattern acceptable to all groups affected by extended grass culture. Stated differently, I feel that what we are now doing with grass could be better done, if conceived and implemented in the light of an accepted grassland philosophy.

That philosophy, however expressed, would take account of at least these assumptions:

1. That the ideal of soil conservation in America will become a fact when farm practice generally accepts and includes in cropping systems grass *as grass* and not as an expedient. For when American farmers become truly grass-conscious they will plant and manage grass in rotation with other crops because they appreciate its intrinsic values. Then, soil conservation, in all its aspects, will follow as a natural consequence.

2. Farmers will accord to grass its proper place in American agriculture when they become convinced that grass culture is economically feasible not only as a dependable source of feed for livestock, but as a soil-improving crop to be reflected in the returns from other crops and as an otherwise legitimate component of cropping enterprises.

3 To this end, all research, educational, and action agencies could well afford to align their forces In such alignment these forces would view grass culture broadly and with respect to its place in farm practice within wide areas. They would give full consideration to the economy of grass in current use, as well as to its value in preserving soil for future generations of society.

This alignment of forces probably could be effected as the result of joint thinking on objectives I would look for constructive thinking among soil and crop specialists, but I would look confidently, also, to the animal husbandman, the nutrionist, the economist, the entomologist, and others. And I would look with equal confidence to organized local or regional groups, as county planning boards and conservation districts, from which would come both thought and action by farmers and business men alike You see I am suggesting no new force, and nothing new with respect to the possible alignment of existing forces I stress merely the need for a philosophy around which to effect the alignment

By such procedure the more extensive use of grass in American agriculture would be considered not only from the standpoint of land-use, which is of utmost importance, but also from the standpoint of grass-use in livestock farming. Personally, I see in grassland agriculture no threat but instead a boon to the livestock industry. If there are misgivings, I think they may be viewed hopefully in the light of the experiences of other livestock countries But in the formulation of grassland programs, potentialities with respect to the livestock industry should and would be fully considered

Grassland agriculture represents a definite advance toward stabilized agriculture. It is not a reversion to pastoral practices It cuts across all phases of agricultural production and therefore commands a high degree of managerial ability It calls for all of the skill usually required in crop production plus the application of that and other skills in the production of crops in rotation with grass The successful establishment and maintenance of a good grass cover requires skillful application of the best agronomic information available, and there is much still to be learned about the breaking and preparation of sodland for succeeding crops in rotations of which grass is a part. Moreover, the utilization of grass, if it is to be made profitable, requires knowledge of a high order pertaining to animal production. A successful grassland farmer, in other words, must be a very good all-round farmer. That, perhaps, is reason enough for clarifying the major objectives of current grassing programs, for upon the farmer himself their ultimate value to America will depend.

My own feeling, as I have tried to make plain, is that whether we are ready to recognize it or not we are headed toward a grassland agriculture. With this in mind I would frankly adopt grassland agriculture as a worthy goal and seek the suggested alignment of forces to insure its achievement.

LABORATORY TEACHING IN BEGINNING COURSES IN CROPS AND SOILS[1]

R. I. THROCKMORTON[2]

LABORATORY teaching in crops and soils merits consideration at this time because it is essential for the future development of these sciences that advancement in teaching keep pace with advancement in research. If teaching methods do not advance in proportion to advancements in the field of research and if the teaching personnel is not of so high a standard as that of the research staff, ultimately the lack of proper training of our students due to poor teaching will be reflected in the quality of research. The successful teacher must lay the foundation for future attainments in research.

Within the last three decades much progress has been made in the sciences of crops and soils, and in closely related sciences. An enormous quantity of accurate subject matter has been made available through research for the use of the teachers of these sciences. Not only have many new facts been established, but many theories that were accepted as facts two or three decades ago have been found to be untrue. We may well ask whether teaching methods have kept pace with research, or whether, through placing so much emphasis upon research, teaching has been neglected.

In discussing the teaching of beginning courses in crops and soils, consideration should be given first to personnel or the teaching staff, second to the subject matter, and third to the methods of presentation. Of these three, the personnel is of greatest importance. Regardless of the quality of the subject matter or the method of presentation, a course cannot be taught to the best advantage of the students unless the instructor has the personality and other qualifications that are essential for success in teaching. As much emphasis should be placed upon training men for teaching as training them for research.

In general, during the last 20 to 30 years, the best trained, most enthusiastic, most inspiring, and most ambitious men working in the fields of crop and soil sciences have devoted most of their time, energy and thought to research. It is only natural that such men have been engaged in research because in this field there is an opportunity to establish some new fact, to develop a new method, to originate a new variety, or to do any one of many other things that will result in public recognition through technical and popular publications. The teacher, on the other hand, has little or no opportunity to establish new facts or to originate new varieties, or to do other things which will bring him such recognition. He must be satisfied with the development of men and with seeing the men he has trained achieve success. The man engaged in research has more frequent opportunities to enter other fields of activity than does the man who devotes all of his time to teaching. Also, in general, the field of research is

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more remunerative than that of teaching. These factors have caused the better men to prepare for research and to follow this field of activity in preference to teaching.

The staff members of the departments of crops and of soils in many institutions devote part time to teaching and part time to research. In my opinion this is a desirable arrangement, and those so engaged are usually among the best teachers, but all too frequently the individual finds himself trying to serve two masters. His research program is exacting and interesting; he is crowded for time; and, although he meets his classes and presents the subject matter accurately and in an interesting and inspiring manner, he does not have time to study his teaching methods or the methods used by his colleagues. He has a tendency to continue his teaching year after year along the same general plan with improvements in the subject matter, but not in methods Time does not permit him to make a study of methods. The research ability of the individual who is devoting a part of his time to teaching and a part to research is directed toward the research problem in which he is interested and not toward research in teaching.

The beginning courses in crops and soils should be taught by the best and most enthusiastic teachers of the staff. Such teachers are giving these subjects in some institutions, but all too commonly it is the practice to have these important subjects taught by inexperienced men and in some cases by graduate assistants or senior students. Since many of the students in agriculture get their first and only impression of the field of crops and soils in the beginning course or courses, it is imperative for success that the teaching method or methods in the class room and laboratory be those that will arouse interest. The inexperienced teacher in the beginning courses usually does not have sufficient background to enable him to inspire a large number of students I do not mean by this statement that the beginning courses should be used for proselyting purposes or as a means of increasing the number of students majoring in crops and soils. They should, however, give the student a definite picture of the entire field of these sciences and stimulate him to further study along the line of each science which applies to his particular agricultural field of endeavor.

There is a closer and more intimate contact between the instructor and the student in the laboratory than in the class room, and for this reason the strongest personalities and most inspirational men should be in charge of laboratory teaching.

Dr. John W. Crist in the PROCEEDINGS of the forty-sixth convention (1932) of the Association of Land-Grant Colleges and Universities, described the type of teachers needed in our beginning courses as follows:

"They must be teachers who can accomplish the subordination of the prevailing material motives of our American youth to the nobler purposes of the quest of truth and true life. They must be teachers possessed of that mysterious power for quickening the young mind, for arousing it to its full capacity and for creative effort, and for endowing it with a refined control over its owner's personal attitudes and activities."

Dean R. L. Watts of Pennsylvania, in a paper at the forty-seventh annual convention (1933) of Association of Land-Grant Colleges and Universities, said, "If the real function of the college is to develop men, then there must be in charge of every class, men of high ideals and high standards, men of courage and strong convictions, men with unblemished characters, men who are willing to sacrifice for students, who are zealous to equip themselves for the most effective place in economic, political and social life."

Dean Watts recognized the basic difficulty in obtaining and retaining good teachers when he said, "Some administrators are disposed to give greater recognition to members of the faculty who are outstanding as research workers than to those who excel as teachers. Unless there is proper recognition by the administration in paying adequate salaries for successful teachers and in promoting them to the academic ranks which they have earned, continuous improvement in instruction cannot be expected."

As long as men can obtain more rapid advancement in salary and in academic rank in research than in teaching, there will be a strong tendency for them to prepare for the field of research. Progress is being made in overcoming this difference and teachers are better prepared and more capable than they were a few years ago, but there is still too much difference in recognition for the best men to be encouraged to enter the teaching profession in preference to entering the field of research. The man who devotes his life to teaching and who is successful in stimulating his students to learn to think and study makes a definite contribution to society and indirectly to research, and he should be rewarded to the same extent as the research man who has made a definite contribution to science.

SUBJECT MATTER

The subject matter for the laboratory in beginning courses in crops and soils should be closely connected with and developed from the lecture and recitation work. There should be a definite relationship between the two, and the laboratory work should supplement the class work. Changes in laboratory work should be frequent enough to keep pace with changes in the class room and with agricultural knowledge and development.

The laboratory courses in crops and soils should have definite objectives and the work should be planned to meet these objectives. In the beginning courses in crops, the student should become acquainted with all of the farm crops and their characteristics, region of adaptation, and uses, regardless of whether or not they are produced in his locality. He should also become acquainted with the standard varieties of the more common crops produced in his region.

The replies received from a questionnaire submitted to the departments of crops and soils show that in 75% of the institutions laboratory exercises in crops consist primarily of a demonstration of principles; while in 20% of the institutions they consist of both a demonstration of principles and technical studies. It is interesting to note that in many of the replies there is indication that most of the labora-

tory exercises in the more advanced courses are largely technical. This is the type of organization that is most valuable in laboratory instruction because most of the students are not ready for the technical studies when pursuing the beginning course and such studies should be primarily in the more advanced courses. The so-called "practical exercises", such as treating seed for the prevention of disease, the inoculation of seed, and the mechanical grading of seed are obsolete in college instruction They belong in the vocational classes

The laboratory exercises in the beginning course in soils should be of such a nature as to give the student a general knowledge of the science of soils with a definite practical application. In most institutions, a high percentage of the students do not take the more advanced courses in soils and for this reason the exercises should be planned and conducted to meet the needs of a majority of the students and not the few who will continue the study of soils.

The replies from a questionnaire show that in approximately 60% of the Land-Grant institutions the laboratory exercises in the beginning course in soils consist primarily of a demonstration of principles In approximately 12% of the institutions the exercises are technical and consist largely of quantitative studies. Dr. L M Turk of Michigan State College made the following excellent statement in a letter relative to types of laboratory exercises: "Technical quantitative studies are not desirable for beginning laboratory courses in soils, particularly in those institutions having the quarter system and only one general course in soils. Time will not permit of much of this type of work. I believe it is more desirable for the general agricultural student to perform exercises consisting primarily of a demonstration of principles. At our institution we have many students (sophomores) taking soils who are not capable of carrying out quantitative experiments with any degree of accuracy In any case, it is a demonstration of principles and these can be ably demonstrated by qualitative or semi-quantitative experiments"

In laboratory courses in soils, as in crops, the tendency is to use quantitative methods in the more advanced courses. In general, such exercises cannot be used effectively in the beginning course.

There has been a decided improvement in the subject matter offered in soil laboratory exercises during the last few years. Many of the exercises formerly used have been found to be obsolete and have been discarded in most institutions. Some of the obsolete exercises are soil mulch studies, determining capillary rise of water, and heat conductivity in the soil.

METHODS OF PRESENTATION

Much improvement has been made in the methods of laboratory teaching. It has been only a relatively short period of time since in most institutions 6 hours or more of the student's time were devoted each week to laboratory work in each crops and soils, and students were required to conduct long, tedious, and monotonous exercises. The laboratory exercises under such conditions meant little to the

student except a task to be completed. Neither has it been long since students were required to write long detailed reports and to make drawings showing minute details on the exercises performed. At the present time, in more than 80% of the institutions replying to a questionnaire, a period of 3 hours or less is devoted each week to laboratory work in the beginning courses both in crops and in soils. Two institutions reported that no time is devoted to laboratory work in soils, but in one of these cases the beginning course in soils is taught by means of a combination of lecture, recitation, discussion, and demonstration methods.

An attempt was made through the questionnaire method to obtain information on the relative merits of individual participation and the demonstration methods of teaching laboratory courses in crops and soils. The replies received indicate that relatively few institutions have attempted to use the demonstration method in teaching the laboratory course in crops. In the laboratory course in soils, it is a common practice to use a combination of the two methods. In most cases where the demonstration method has been tried it is considered to be superior to the personal participation method for certain types of exercises and inferior for other types. At Ohio State University the demonstration method is used in teaching laboratory courses in both soils and crops and is thought to be superior to the personal participation method.

Written reports on laboratory exercises are not required in soils by about 27% of the institutions, while only 18% do not require such reports in crops. It is interesting to note that practically all of the institutions have discontinued requiring detailed drawings in connection with the reports.

It has been our experience, especially in teaching the laboratory course in soils, that it is more effective to give a short written quiz each week covering the exercises of the preceding week than to require written reports. This method has not only been found to be more effective but also to result in a saving of time for the instructor and the student. I believe, that with certain exceptions, such as field trips and a few special exercises, the instructor is not justified in requiring written reports on laboratory exercises in the beginning courses in either crops or soils.

It is commonly thought that the use of drawings in connection with laboratory reports causes the student to be more accurate and more observing. Dr. H. C. Sampson of Ohio State University, after conducting considerable research on this subject, made the following statement. "We have not found the elimination of drawing exercises to detract either from the amount or the accuracy of observation by the student."

It is fully realized that the preceding suggestion of decidedly reducing the requirements for written reports on laboratory exercises is a distinct departure from the method now in use. I recommend the use of the short quiz method at least as a partial substitute for the written reports. Advantage must be taken of every opportunity to improve our teaching methods. Dr. W. L. Burlison of the University of Illinois states in the PROCEEDINGS of the forty-third annual con-

vention of the Association of Land-Grant Colleges and Universities, "No finer advice on this has come our way than the thought left us in 1897 by Whitman: 'Let us here take warning of one danger to which we are all liable—the danger of adopting ideals and adhering to them as finalities, forgetting that progress in the model is not only possible, but essential to progress in achievement. . . . The head may thus become stored with a lot of fixed mental furniture, and the possessor become the victim of an illusion, from the charms of which it is difficult to disenchant him. He falls into admiration of his furniture, taking most pride in its unchangeableness. It was, perhaps the best to be found in the market at the time of installment, and he finds pleasure in the conceit that what was the best is and must remain the best. He sees new developments in the market, but his pride and inertia content him with the old. The illusion now takes full possession of him, and every departure from his ideals seem like abandonment of the higher for the lower standard of excellence. His conceit grows instead of his ideals, and every annual ring added to its thickness renders it the more impervious'."

Methods used in teaching the laboratory in the beginning courses in crops and soils need serious consideration especially with regard to requiring the student to acquire certain technic in the laboratory. A large percentage of the students taking such courses will not become technical men in either field and the time required for them to learn certain technic is largely wasted. The time available for such courses is limited and can be used to better advantage in other ways than developing technics. This is not true in the case of the more advanced courses where the students are specializing in a particular field and need to acquire the technics of their field of study.

The instructor needs to have clearly defined objectives of what he wishes to accomplish. If he wishes the student to acquire skills, then the student must conduct many exercises individually in order to obtain these skills. However, if he wishes the student to obtain a broad knowledge and understanding of the subject and to learn how to apply that knowledge, a large amount of individual participation in the laboratory should not be necessary There is a tendency, when using the individual participation method of teaching laboratory courses, for the instructor to exact certain technics without thought of the possible value of such technics to the student during the remainder of his formal education or in after life I believe the instructors in crops and soils have gone much farther in the elimination of technic development in the beginning courses than have the instructors in most related sciences as botany, zoology, and bacteriology, although in some institutions this type of laboratory procedure has been almost entirely eliminated in the teaching of these basic sciences.

There is ample research evidence available to show that in beginning courses in basic sciences the demonstration method of teaching in the laboratory is superior to the individual participation method, and I can see no sound reason why the results of the research studies in teaching of the basic sciences will not apply to the teaching of crops and soils. Dr. John Dewey made the following statement relative to the methods used in laboratory teaching and of the types of

exercises frequently used: "Our attention may be devoted to getting skill in technical manipulation without reference to the connection of laboratory exercises with a problem belonging to the subject matter. There is sometimes a ritual of laboratory instruction as well as of heathen religion."

I do not wish this discussion to be interpreted as meaning that I think there is no place for written reports and for the individual participation method of instruction in teaching the laboratory in beginning courses in crops and soils. I should, however, like to have it interpreted as a challenge of whether we have definitely established specific objectives in our laboratory teaching, whether the objectives established are correct in view of the fact that most of the students will not continue in the field of either crops or soils, whether the laboratory exercises are of the character they should be to meet the objectives, and whether we have applied scientific studies to our teaching methods to the same extent as we have to our research problems in crops and soils.

SOME RESEARCHES IN EDUCATION AT THE UNIVERSITY OF MINNESOTA[1]

H. K. WILSON[2]

THE first institutions of higher learning in the United States were more or less reserved for the use of wealthy individuals. Not many of the poorer classes aspired to attend a university. The development of the land grant colleges revolutionized the entire system of higher education. Today with the opportunities afforded through the National Youth Administration, scholarships, prizes, and various student subsidies, every boy or girl of average intelligence may hope to attain society's mark of distinction, the bachelors degree.

With the increased attendance in our universities, new curricula were developed. Demands for specialized types of training increased. No longer was it enough to know to parse Latin and Greek; practical information was demanded As with all major educational movements there was a decided tendency to swing too far to the left. There were those who argued that a farm boy did not need training in economics, psychology, or similar social science courses. In other words, all that should be taught a boy were the manipulative devices enabling him to make money. It did not occur to many that perhaps there were advantages in university training other than learning a vocation.

Today at the University of Minnesota there are more than 15,000 full-time students, ranking it as the third largest educational institution in the country. When one considers the vast number of young people involved, he wonders how well the University is meeting the challenge raised by increased enrollments. Should all of these young people follow a set curriculum? No one believes they should, but there are many who believe the various curricula should be rather rigid without too many loopholes for the student with ideas of his own. The problem of the fixed curriculum is but one of the many confronting our educational institutions today. There are numerous problems relating to increased efficiency in teaching. It is some of these that are discussed here with regard to experimental work at the University of Minnesota as efforts are made to raise the standards of instruction.

THE MINNESOTA COMMITTEE ON EDUCATIONAL RESEARCH

The University of Minnesota has been studying its own problems in a systematic way since about 1919. The first agency to be set up was known as the Survey Commission, and one of its first problems

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St Paul, Minn. Published with the approval of the Director as Paper 384 of the Misc. Journal Series. Presented at the meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication December 3, 1938.

[2]Agronomist. The author wishes to express his appreciation to Dr. E. M. Freeman, Dean of the College of Agriculture, Forestry, and Home Economics, and to Dr. Palmer O. Johnson, Professor of Education, for their valuable assistance in the preparation of this paper.

was a study of the probable growth in student enrollment at the University in the next 25 years. When Dr. L. D. Coffman became President in 1921, other studies were undertaken dealing with such problems as faculty-load, university income and expenditures, etc. In 1921, a Committee on Student Personnel was appointed. While this committee was temporary, one of its recommendations was that a permanent committee should be set up to study educational problems. This recommendation was followed and in 1924, President Coffman created the Committee on Educational Research, a committee which has been continuously active since its initiation

The membership of the Educational Research Committee consists of 13 persons, drawn largely from the deans of the several colleges and a small group of interested professors. The committee holds no allegiance to any college administration or to any faculty. Its function has been to study the problems of the University, including administrative, instructional, and student personnel problems, and to publish the findings. A large and impressive list of publications has been issued from this source (14, 15, 16).[3]

Briefly stated the procedure in the investigation of a problem consists in the interested college, department, or individual proposing the problem and requesting the cooperation of the committee for financial aid and technical assistance. If accepted by the committee, the request for the necessary funds is submitted to the President of the University for his approval. If the request is granted, the problem is attacked jointly by the sponsoring agency and the technical assistant from the committee, a man trained in the methods of educational research and capable of assisting in laying out the plan of investigation and in collecting, analyzing, and interpreting the data

During the entire 14 years since its appointment the committee has functioned in furthering educational researches based upon scientific modes of attack. It is to some of these researches that I shall refer

REVIEW OF RESEARCH STUDIES MADE

In order that I may illustrate the wide range of educational investigations undertaken, let me briefly refer to a few of the pertinent studies made by various members of the University staff.

Koos (11), who studied the junior college movement, noted its rapid development during recent years. He states that the aims of the junior college are to do the first two years of college work satisfactorily, to give pre-professional work, to give occupational training to those not going farther in school, to popularize higher education, and to integrate better the high school and senior college.

Hudelson (5), in a study of class size at the college level, used for his investigations 59 experiments involving 108 classes under 21 instructors in 11 departments in 4 colleges of the University of Minnesota. He compared 6,059 students (4,205 in large classes, 1,854 in small classes) with man-to-man comparisons of 1,288 pairs of students, matched as to intelligence and scholarship. Forty-six,

[3]Figures in parenthesis refer to "Literature Cited", p. 248.

or 78%, of the experiments favored more or less the large class while only 22% favored the small class. In the man-to-man comparisons at every intelligence level and at every scholarship level, the paired students in the larger classes did work superior to that of their mates in the small classes. Students studied favored the small class while faculty members preferred a medium-sized class. Hudelson concluded that the influence of class size upon student achievement as measured by tests and marks was too slight to warrant the cost of small classes, and that teachers should attempt to adapt their methods of instruction to class size.

Johnston (10) tested 366 Twin City high school graduates and found that low high school records alone indicated 66 of the 148 failures made in the university, low standing in freshmen themes alone predicted 95 failures, lack of advanced studies alone pointed out 95, and low mental test scores indicated 39 failures. Of the students who were low in all of the four measures, only one graduated. Johnston concluded that no one of these predictive measures could be used alone with success In further studies (12) of 1,030 Twin City high school graduates, high school rank and mental test scores gave a correlation of successful prediction of University success of +.70 for men and +.67 for women. The error of prediction for those below the ability threshold set by the University was 7% of the whole group.

Paterson (13), in researches with types of examinations, reports that a real objective examination must adhere to the following principles: Each question must be a unit, each question should be short and permit a short answer, ambiguous questions must be avoided, the possibility of guessing must be eliminated He stated that a successful objective examination offers objectivity, comprehensiveness, reliability, and economy.

Chapin (1), who investigated the extra-curricular activities of University of Minnesota students, reports that the most active students were the best students, 40% of the students were in fraternities or sororities, women were in more activities than men, upper classmen were in more activities than freshmen, 35% of the students earned money, 33% were members of religious groups, students in most activities were most intensely active, the best students engaged in intellectual activities, the poorer students were interested in fine arts, music, and dramatics.

Diehl (2), in a paper discussing health in relation to scholarship, reported that defective hearing of extreme grade, overweight, flabby musculature, and anemia were physical defects which occurred with sufficiently greater statistical frequency in the probation groups than in groups of superior students.

Eurich (3), investigating types of examination, found the four types, essay, completion, multiple-choice, and true-false to be of equal validity. However, he favored the completion and multiple-choice tests as being the most satisfactory types.

Haggerty (4), studying 50 candidates for entrance into the Medical School, obtained a correlation of .60 between the Scott omnibus test and the marks earned by the same students in their first quarter at

the University. The Thorndike reading test gave a correlation of .62 with the first quarter marks, while the correlation between grades received in the Science, Literature, and Arts College and those received in the Medical School was .49.

CURRICULAR PROBLEMS IN SCIENCE

Like many other institutions, the University of Minnesota for years has had a definite sequence of botany courses listed as prerequisites for courses in the College of Agriculture For example, a student in the College of Agriculture could not pursue a course in grain crops without having completed 9 hours of botany These 9 hours represented three 3-credit courses Instructors in agronomy had noted the seeming lack of understanding of certain botanical principles as evidenced by class performance in the more applied courses. Obviously, a gap had developed between the botany courses and those in farm crops.

In 1928, Johnson presented a Ph D thesis entitled "Curricular Problems in Science at the College Level" Later, this thesis was published (6) in book form in 1930.

The University of Minnesota was extremely fortunate in having a man like Johnson available. Thoroughly conversant with the problems of teaching science and the inter-dependence of botany and farm crops, together with his training in educational research methods, he was admirably suited for a study of the botany courses and their relationships to the College of Agriculture curricula.

Johnson began his investigations with the first courses in botany as taught in 1870 and traced their development along with the changes in related courses in agriculture from that date until 1928.

Since the development of the College of Agriculture at the University of Minnesota, botany has been considered basic. The number of required quarter credits, 7½, was increased gradually to 24, then reduced to 9, the required number when the study was made.

Johnson made a careful analysis of the subject matter content of the required botany courses and of certain agricultural courses including general farm crops and a course in grain crops While, in a sense, it is impossible to draw definite limitations on what constitutes botany as such and that which is strictly agronomic, Johnson did make such a classification. He divided the subject matter offered in the botany and the crops courses as shown in Table 1.

The botany courses and all of the agronomy courses are 3-credit units. Farm crops 1 is a general course required of all freshmen and does not have a botany pre-requisite. Each of the other courses required the 9 credits of botany and was open to sophomores, juniors, and seniors.

Included with the study of agronomic courses were several others in agriculture and forestry. None of the 21 courses dealt with either comparative morphology or algology, although nearly one-third of the time spent in botany embraced these subjects. Obviously, much of the average student's time was spent in subject matter of little application in the College of Agriculture. It should be noted that while the classification indicates that no comparative morphology or

TABLE 1.—*Percentage of time devoted to different botanical categories in botany and crop courses.*

Course	Morphology of flowering plants	Comparative morphology	Histology	Cytology	Physiology	Ecology	Physical ecology	Plant pathology	Taxonomy of flowering plants	Algology	Mycology	Bacteriology	Genetics
Botany 4 5 6	18	19.5	16.5	4	-	—	19.5	—	—	9	9	25	2
Farm Crops 1	25		---	-	10	6		4	15		-	1.0	1
Grain Crops 121	21	--	-	—	5	9	—	1	18			--	3
Corn+Potatoes 122	19		—	-	11	16	---	2	4		-	—	7
Forage Crops 123 .	6		-	--	5	17	9	3	4			1.0	5
Plant Genetics 131 .	6	-		10	--		—		—	-		—	84

histology was taught in the agronomic courses, this is not entirely correct. At present all of our crops courses involve such material as pollen tube growth, double fertilization, cell structure in relation to lodging of small grains, and many other applied phases of botany. As a result of Johnson's studies, the botany courses were revised to include the following: A general 4-credit course required of all agricultural students and pre-requisite to elementary 3-credit courses in plant physiology, ecology, taxonomy of flowering plants, and morphology As now arranged, the first course in botany is planned to give the beginning student an appreciation of the importance of plants to human society. No longer is an attempt made to give details of a large number of the components of botany These are reserved for the later courses which follow botany 1 Most students are required to choose at least two of the alternative courses and many elect additional ones. The instructors in crop courses at University Farm believe an improvement in student preparation has resulted from these changes.

As botany was not a pre-requisite for freshmen enrolling in general farm crops, it was possible to compare the records of two groups, one having had botany and the other not. While the number of students compared was small, 7 with botany pre-preparation and 9 without, the results are indicative, as shown in Table 2.

A comparison of the average achievement scores of 86.7 ± 10.1 with botany and 85.9 ± 10.5 without botany preparation indicates no significant advantage of the botany training to this particular group of students. Comparisons with students enrolled in elementary fruit growing and vegetable growing as taught in the Horticulture Division gave similar results.

In another phase of the research, Johnson studied the retention of the different phases of botanical knowledge by agricultural students. While different groups were studied, the principles should operate to illustrate retention. In Table 3 are given the results of this study.

TABLE 2.—*Achievement of students in general farm crops with and without previous preparation in general botany 4-5-6, fall quarter, 1927.*

With botany				Without botany			
Student's No.	Honor point ratio	Botany test score	Achievement test score	Student's No.	Honor point ratio	Botany test score	Achievement test score
1	0.916	57	99	1	1.540	8	99
2	0.769	123	96	2	2.151	0	97
3	0.949	27	93	3	0.352	0	91
4	1.674	73	87	4	1.454	14	89
5	1.068	78	86	5	2.096	3	88
6	0.031	26	79	6	0.785	7	85
7	0.376	9	67	7	0.357	0	85
				8	−1.000	0	78
				9	0.166	0	61
M	0.826	56.1	86.7		0.878	3.6	85.9
S.D.	± .483	±36.3	±10.1		± .96	±4.8	±10.5

TABLE 3.—*Retention of botanical knowledge as indicated by correct responses to test items classified in the several botanical categories.*

No. of students	Botany 4-5-6		Comparative morphology	Histology	Algology	Cytology	Taxonomy of flowering plants	Mycology	Physiology	Bacteriology	Genetics
	Year taken	Months after completion									
126	1927-28	Freshmen	1.9	4.4	2.4	2.9	10.7	14.5	11.1	39.5	22.2
29	1926-27	0	78.1	72.9	76.9	75.3	77.9	85.7	86.2	87.3	82.8
24	1926-27	3	41.4	36.5	36.9	31.7	58.6	64.6	65.2	86.2	86.2
29	1925-26	15	18.2	19.9	23.6	29.5	39.2	47.8	51.5	82.2	82.8
22	1924-25	27	12.1	18.7	19.6	24.4	39.5	45.1	49.5	81.5	95.5
No. of test items			70	50	26	25	72	15	33	6	1

It is believed that these scores are modified largely by the courses following botany. For example, as the courses following botany gave little morphology, histology, or algology, the percentage of retention was lower than for groups which were encountered in later courses. Conversely, a student majoring in agronomy would receive more and more training in the taxonomy of flowering plants, plant physiology, and genetics. Likewise, the retention in these phases was greater as indicated.

In detailed studies made in the College of Agriculture of college aptitude and achievement, Johnson (7) concluded that (a) student achievement during the first quarter in college is an excellent index of survival; (b) the achievement records and ability of students who did not plan to graduate were substantially less than for the average of the entire student body; (c) for the group of students studied, the

college aptitude test appeared to be of limited value in predicting what junior college students will do in the senior college; (d) coefficients of correlation between high school percentile ranks and honor point ratios were more reliable than those between the college aptitude test and honor point ratios; (e) those agricultural students receiving all their elementary training in rural schools showed greater achievement than students who had their elementary schooling in villages or cities; (f) students from farm homes had significantly lower percentile ranks, on the college aptitude test, but their achievement equaled or exceeded that of students from the largest cities; and (g) apparently no relationship existed between ability and time spent in study, recreation, or self-support.

The improvement of types of examination is a subject confronting each teacher. If poorly planned, the old true and false test may be of little value and frequently is of less value than the so-called essay or subjective type of examination. A well-planned examination is one which challenges even the best student. Above all, it must be valid and the instructor must take great care that the questions are clear to the student. The writer has used the new types of examinations for several years, never giving the same examination twice. Never yet, have I given an examination which was not faulty. Always, I find it necessary to rule out certain questions because, while they were clear to me, they proved ambiguous to the student. The instructor should always check the answers to learn if the entire class is out of step or not. The instructor who fails to do this will get a real surprise if he checks the examination replies with care.

Dr. Palmer Johnson (8) has reported on tests and examinations used at the University of Minnesota. The examination problem is one which the Committee of Educational Research has studied for several years The General College of the University has been used as a testing ground for many new ideas in examination procedure.

Under the plan proposed by Johnson (9), a set of examination questions is not the work of one man but of several. In the large classes of the General College, the examination assistant and the instructor prepare the questions. These questions must be approved by a counselor especially trained in education and capable of passing upon the reliability of test procedures. Recently, a fourth individual, a coordinator has been added. The coordinator is a staff member whose job it is to coordinate the various curricula within the college over a period of years. In many cases the questions are submitted to several staff members within a subject matter division to check upon the validity of each question. This may appear unnecessary to one accustomed to handling the entire job alone. However, test results show that it is important that these checks be made if the examination is to be fair to the student and to the instructor alike.

The five general classes of examination questions may be grouped as follows:

1. Typical objective questions. To be scored with a key. These questions include true-false, multiple choice, and other familiar types.

2. Simple-response questions. These questions require the stating or listing of factual data. Examples are "name", "list", and like types.

3. Uniform content, variable response questions. These questions require a phrase or sentence in response. Examples are "define", "illustrate", and "classify".

4. Variable response and variable content. This type of question requires a more elaborate response, allowing considerable scope in the selection of the answer. Examples are "comment on", "interpret", and "state a question and answer it".

5. Miscellaneous questions. This type includes mathematical problems, translation, marking of maps properly, etc.

Among the primary outcomes of teaching a course are (a) giving the student a vocabulary, (b) teaching him principles or other factual information, and (c) training him to apply the principles or other factual information in the solution of situations or problems. In addition, some courses require the development of certain abilities, as the ability to determine properly the market grade of a sample of wheat or hay. Obviously, the examination procedure which gives the clearest picture of the student's ability to meet life's problems is probably the best to use. The more real one can make the question, the more valuable it should prove in measuring the student's grasp of the subject matter in question

PREDICTION OF ACHIEVEMENT OF STUDENTS IN THE COLLEGE OF AGRICULTURE

In the fall of 1933 34, Dean E M. Freeman and Dr. Palmer Johnson initiated a study directed at the prediction of achievement of freshmen entering the College of Agriculture, Forestry, and Home Economics. A battery of tests consisting of the cooperative test in algebra, the cooperative test in science, the Johnson science application test, and tests in science, mathematics, and English prepared under the auspices of Dr. Boardman of the University High School were administered to entering freshmen. Scores from these tests, the high school ratings, and the ratings from the college ability tests were used as measures of prediction. The same battery of tests, with the exception of the cooperative test in science, was administered to freshmen entering in 1934-35. From these trials it was found that the high school percentile rank ratings, the Johnson science application test, and the cooperative algebra test constituted the best combination for predictive purposes. The other measures made no independent contributions. Multiple correlations between the combination of the Johnson science, cooperative algebra, and high school percentile rank and honor-point ratios have been obtained for each of the groups studied over the 4-year period at various stages in the college career as follows: (a) The freshmen entering in 1933-34 have been followed through 4 years; (b) the freshmen entering in 1934-35, 3 years; (c) the freshmen entering in 1935-36, 2 years; and (d) the freshmen entering in 1936-37, 1 year.

The findings over the 4-year period have been consistent. A multiple correlation of .72 has been obtained between the measures of prediction and honor-point ratios at the end of the freshmen year.

For each of the last two years, the predictive measures with their corresponding probability values have been placed in the hands of

the advisers of the college for purposes of directing students with respect to their curricular allocation at the time of entrance to the University.

This year the chief problem consists in integrating the total findings from the 4-year study and exhausting the information provided by the observations. Dean Freeman and Dr. Johnson are preparing a bulletin incorporating the principle findings and their uses. It is hoped that this publication may be available within the coming year. A considerable number of inquiries from other colleges of agriculture indicate wide interest in this study, the first comprehensive one of its kind in this field.

As many know, a large mail-order house has granted large sums of money to colleges of agriculture for the purpose of aiding farm-raised boys to secure a university education.

At the University of Minnesota we do not select these boys until after they come to college. We reason that a boy needs to have enough money to make a start. Following this, the scholarships should enable him to remain in school This plan permits the giving of the Freeman-Johnson predictive tests. On the basis of these tests, it is possible to predict with surprising accuracy the probabilities of a student earning certain marks in college For example, the tests may indicate that a student has 12 chances in 100 to earn an average grade of B or better. Another student on the basis of his high school record and test scores may have a predictive score of 0 chances in 100 to earn an average grade of B. He may have a reasonable number of chances to make a C average, the required passing grade. The information derived from these tests, together with personal information, makes it possible to grant the scholarships to students who appear most promising. Also, the information is of great value to the adviser when a student encounters difficulties with his courses. The adviser is better able to determine whether the student is a plain loafer or does not have the mental capacity for making a satisfactory record in college.

CONCLUSIONS

The day when the educator and the psychologist alike were apart from the fields of so-called technical education has passed. Frequently these men cooperate with the teacher of sciences in the making of educational studies. Many so-called educational experiments have been casual and often poorly planned observations which led to hasty and ill-advised conclusions. Today, educational problems are being met in a scientific manner. Just as much research ability is required to conduct an adequate and comprehensive research in education as for an adequate study of how to control noxious weeds. The biological scientist must hold his mind open to the possibilities of improved methods of teaching. He should welcome a new idea in education as warmly as the discovery of a new physiologic or genetic principle in crops research. If the research agronomist will but approach educational problems in this manner, then we cannot fail to witness a renaissance in our agronomic teaching.

LITERATURE CITED

1. CHAPIN, F. S. The Significance of Extra-curricular Activities. (In Problems of College Education.) Minneapolis: University of Minnesota Press. (Pages 351–357.) 1928.
2. DIEHL, H. S. Health and scholastic achievement. U. S. Public Health Rpt., 44:No. 50. Dec. 1929.
3. EURICH, ALVIN C. Four types of examinations compared and evaluated. Jour. Educ. Psych., 22:268–278. 1931.
4. HAGGERTY, M. E. Tests for applicants for admission to University of Minnesota Medical School. Jour. Educ. Psych., 9:278 286. 1918.
5. HUDELSON, E. Class Size at the College Level. Minneapolis: University of Minnesota Press. 1928.
6. JOHNSON, PALMER O. Curricular Problems in Science at the College Level. Minneapolis: University of Minnesota Press. 1930.
7. ————. Aspects of Land Grant College Education. Minneapolis: University of Minnesota Press. 1934.
8. ————. The kinds of tests and examinations used at the University of Minnesota. (In Tests and Measurements in Higher Education. Ed. by Wm. Gray.) Proc. Inst. Admin. Officers of Higher Institutions. 1936.
9. ————. Methods used in improving tests and examinations at the University of Minnesota. (In Tests and Measurements in Higher Education. Edited by Wm. S. Gray.) Proc. Inst. Admin. Officers of Higher Institutions. 1936.
10. JOHNSTON, J. B. Tests for ability before college entrance. School and Society, 15:345–353. 1922.
11. ————. Predicting success or failure in college at the time of entrance. School and Society, 19:773 776; 20:27 32. 1924.
12. KOOS, L. V. The junior college movement. New Republic, 36:22 24. 1923.
13. PATERSON, D. G. Improving the examination function in teaching. Bul. Univ. Minn., 31:47–56. 1927.
14. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1928–30. Bul. Univ. Minn., 34: No. 7. Feb. 1931.
15. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1930–32. Bul. Univ. Minn., 36: No. 1. Jan. 1933.
16. REPORT OF THE COMMITTEE ON EDUCATIONAL RESEARCH FOR THE BIENNIUM 1932–36. Bul. Univ. Minn., 40: No. 38. April, 1937.

SOME EFFECTIVE AIDS FOR AGRONOMY EXTENSION IN MICHIGAN[1]

R. E. Decker[2]

SOME people think of the extension worker as a teacher whose classroom is the rural community bounded possibly by county or state lines, and our students as those people living within these boundaries who are interested in agriculture. This is a simple way of explaining our duties, but simplicity ends with that explanation—the actual carrying on of extension work is much more complex.

The undergraduate student goes to classes at a definite time, at a definite place, and often with no definite ideas or experience regarding the subject which he is taking under a definite instructor. If the latter fails to make the subject interesting, it will not greatly affect the size of his audience, at least not during that particular term or semester.

The extension worker meets his group at places calculated to suit the convenience of those interested and these meeting places vary in seating comfort, lighting arrangements, temperature, and other conditions which can influence the attention of those in the group. People attending are generally experienced and often have well-established ideas regarding the subject matter to be presented. They are not backward with criticism. If their ideas are erroneous we must tactfully find a common point upon which we can agree and proceed from there to set up a favorable reaction to the correct practice. In short, our aim is to present correct information in such a way that it will encourage folks to go home and make use of it.

In carrying out extension work we cannot hope to reach everybody through our own personal contacts. County agricultural agents can receive the information from us and assist in distributing it within their counties. They in turn can relay information to Smith-Hughes instructors or to individual farmers whom they find willing and capable of conducting meetings in their communities. More will be said about this later.

We hardly dare to expect that we are going to secure 100% action with one presentation of our subject matter. Personally, I am not certain that high-pressure salesmanship which would secure such results is desired with some projects. Although extension workers endeavor to pass out information which has been well proved experimentally, the extension agronomist is often confronted with many situations affected by soil and climate, as well as the different customs of farmers in carrying out cultural practices.

It was pointed out that the conditions under which meetings are held often will influence the results obtained. About 18 years ago the Dairy and the Farm Crops departments at Michigan State College decided that there was a need for a state-wide campaign to acquaint

[1]Contribution from the Department of Farm Crops, Michigan State College, East Lansing, Mich. Also presented at the meeting of the Society held at Washington, D. C., November 16, 1938. Received for publication December 27, 1938.

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people with the benefits of alfalfa and the proper cultural practices to grow the crop successfully. It was decided to conduct this campaign by counties and that the meetings would reach more people and be more effective if they were held on the farms. In general, these were barn meetings and the particular location in the barn was the cow-stable. The farmers left their own work for a couple hours, coming to the meetings without having to take the trouble of changing their clothes. One extension worker gave a talk on the problems confronting the dairyman, while another explained the methods of growing alfalfa. These meetings were very popular, and played an important part in raising Michigan's alfalfa acreage from less than one hundred thousand to well over a million.

An extension meeting where there are questions from the group, as well as the relating of experiences, is always considered ideal and that is precisely what we secured in these barn meetings. It has always seemed to the specialists who have attended these meetings that there was more discussion when these meetings were held under the exceedingly informal conditions described than where held in halls or other more formal meeting places. The alfalfa campaigns are recalled to emphasize the point that the barn meeting proved an effective aid in getting response from the farmers in a great increase of the alfalfa acreage. The nearer we can bring our meetings to the subject under discussion, the easier it is to arouse interest on the part of those in attendance

During the last three years we have been carrying on another crops project which is in line with the foregoing statement This is the hybrid corn demonstration. When these were started in 1936 it was evident that the county agricultural agents were already quite busy with the agricultural conservation program, in addition to their other work. It was, therefore, proposed to them that the hybrid corn demonstrations be arranged in cooperation with the Smith-Hughes agricultural schools wherever such schools were interested. The plan as finally worked out was as follows: The Smith-Hughes agricultural teacher selected a boy who was to conduct the cooperative demonstration. Agreement forms were drawn up in which the duties of each of the cooperators, the boy, the agricultural teacher, the county agricultural agent, and the extension specialist in farm crops were outlined, and these agreements were signed by each party and each retained a copy. At first thought this might seem to be a lot of unnecessary procedure, but it seemed well to have such an understanding of the proper relationship of all parties concerned. For my part I was particularly interested in the boy, that he should realize that he had a responsibility and that the others had their part to perform, as well as himself. He agreed to plant the demonstration according to plans furnished him and to harvest it under the supervision of his agricultural instructor. It was agreed that wherever advisable the agricultural instructor and the county agricultural agent would cooperate in holding a meeting at the demonstration plat at time of harvest. If necessary the extension specialist in farm crops would assist at these harvest meetings.

In the first place the hybrids which are furnished are those which in experimental trials have shown some evidence of being adapted to the particular locality. However, we have included some which we knew were not adapted and others which neighboring states were growing along the border. For example, in our southern tier of counties we gave the boys certified northern Ohio and northern Indiana hybrids, as well as the best of the early certified Illinois strains. Wisconsin hybrids were likewise quite generally used. It is our desire to acquaint corn growers with the best hybrids available regardless of where they were developed.

At harvest the usual procedure has been for the Smith-Hughes instructor to have his agricultural students present and in practically all cases the agricultural agent and a representative of the Farm Crops Department of the College have also been there. A 10-rod row of each hybrid is harvested and weighed and samples taken for moisture and shelling percentage determinations The students and farmers in attendance look over the different hybrids and pass judgment upon them. The "how and why" of hybrid corn is explained, usually by the extension worker from the College. The students take the samples back to their school laboratory and determine the moisture and shelling percentage, the boy who conducted the demonstration makes out reports and forwards one to each of the other cooperators. The extension specialist summarizes all reports and sends this summary to each of the other cooperators.

We started with these demonstrations in the two southern tiers of counties, but they have increased and during this year we had 00 of these planted, held 81 meetings at harvest, in 25 counties.

The interest is increasing in this type of demonstration. Having a different group of students each year, the Smith-Hughes instructor likes to continue the project. Attendance of farmers at the harvest meetings is increasing. In many cases the county agricultural agents want the farm crops specialist present. It will probably be necessary for the agents to conduct many of these harvest meetings themselves in the future, if demonstrations continue to increase in number, and even if they do not increase it is to the agricultural agent's advantage to conduct the meetings to a large extent.

The value of these demonstrations can be summarized as follows: (1) They provide another valuable contact between the farmers and the extension service; (2) they acquaint people with hybrid corn; (3) they show that all hybrids are not good hybrids; (4) they acquaint students with demonstrational methods; (5) these plats, planted over a wide area, give the extension worker a better idea as to range of adaptation of the hybrids and, better still, a good idea as to what the farmer thinks of various hybrids; and (6) they are interesting a number of good boys and their fathers in hybrid seed corn production, as well as stimulating an interest in other projects.

Work quite similar to this is being carried on with the schools with beans.

A valuable aid in meetings other than field meetings is found in pictures. The use of slides has become quite general among extension workers and they are more effective where the pictures have been

taken of demonstrations or crops within the county or state. The colored picture usually is very effective in crops work, is of more interest to the audience than plain black and white, and provides opportunities for demonstrating certain contrasts that do not show in ordinary pictures. The 35-mm camera from which slides or enlarged pictures can be produced seems more suitable for the extension worker who during a field trip can take pictures of a variety of crop projects and at the end of the season can assemble those pertaining to definite projects and use them during the season of indoor meetings. Moving pictures do not so readily lend themselves to this plan and another thing to consider is that we have much competition from excellent moving picture shows. The word "movie" seems to carry with it the idea of entertainment. Needless to say, pictures should be good or not used at all.

Much has been said in the last few years about the discussion meeting and it was pointed out in a previous paragraph that the ideal meeting was where you could get some discussion. We try to have folks feel that the meeting is theirs, but this is at times a difficult thing to do. If we can get people at the start of a meeting in the state of mind where they feel that they are contributing to its success the stage has been well set.

Several years ago we made our first use of a teaching aid generally associated only with class rooms, namely, an examination. This device, used first at district conferences of county agricultural agents and, since then, at numerous farmers meetings has proved not only effective but, contrary to its class room reputation, exceedingly popular.

The test, as we use it, is made up of the objective type of questions or problems either multiple choice, in which a number of answers are given to a question, one of which is correct; or simple statements which are to be checked as "true" or "false".

A mimeographed copy of the complete set of questions or statements is handed to each member of the group at the beginning of the meeting and time is given for each to note or check his answers. Then the leader takes up each problem and uses it as the basis for group discussion of the particular topic involved.

For example, the statement, "Alfalfa is less likely to be injured by close grazing in late October than it is in mid-September"; true in Michigan, provides an excellent lead for a pointed discussion on the fall management of alfalfa, particularly with reference to the fall storage of root reserves to carry the plants through the winter and initiate vigorous growth in the spring.

Similarly, at a sugar beet meeting, the multiple choice statements that "sugar beets should be grown in 18-, 22-, 24-, or 28-inch rows" stimulates considerable argument as to the merit of the various row-widths, and gives the specialist an opportunity to emphasize information which will enable growers better to exercise their judgment when beet planting time again comes around.

Why is the objective test an effective extension teaching aid? First, I should say, is that it is a stimulus to thought right along the lines which the discussion leader wishes to emphasize whether a

group member takes part in the discussion or not. Second, it stimulates argument and discussion in which everybody takes part. Often those who have checked a statement differently than the leader will defend their position. This draws arguments from others in the group. The result is that, at the close of the meeting, everybody has had something to say, the subject matter has been thoroughly discussed, and people leave feeling that they were really a vital part of the meeting, as indeed they were. However, they should not be permitted to leave until there has been placed in their hands a key sheet upon which are the correct answers to each of the questions, along with supporting evidence for those answers

Thirdly, with the test problems as an outline, the discussion can be very broad and comprehensive without straying off down blind alleys and crooked by-paths that lead nowhere. When discussion wanders it can always be brought back by taking up the next specific problem.

It may be added that discussion has always been so keen at these meetings that about 20 questions or statements will keep interest at high level for 1½ to 2 hours

It should be emphasized that the questions or problems are not designed to test the individuals who participate, except perhaps for their own information Their answers are not taken up and checked by teacher The answers which each individual has given are his personal concern only. The big idea is that here is a sound pedagogical aid to the stimulation of thought and free discussion which is simply bound to bring out a lot of sound information, as well as to develop the personalities of everyone who takes part

This method is particularly suited for use with groups of people of less than 50 in number and when the meeting is held where tables or desks are available for writing. It was used in two of our counties where farmer local leaders were taking the work back to groups in their communities. The county agricultural agent and extension specialist met the leaders once a month for four months and four projects of our crops program were successfully explained to these people during that winter.

One of the first communities where this method was used is located about 40 miles from the college in a dairy and poultry section. A day meeting was held during each of December, January, February, and March and at each meeting some crops problem was taken up by the "true" or "false" method. The attendance varied from a minimum of 24 to a maximum of 28, and 23 farmers attended every meeting. Incidentally, the last meeting was held during the worst blizzard of the winter and three-fourths of the men walked to the meeting. Also, on this stormy day we had our largest attendance.

The county agricultural agent of one county has requested us to prepare a set of "objective" statements for his five Smith-Hughes agricultural teachers who are going to hold farmers meetings at their schools during the winter. The agricultural agent and a crops extension specialist will meet with all the instructors sometime prior to the meeting and go over the work. Incidentally, considerable care must be used to make sure that the statements used are clear, pointed, and free from catches or ambiguity.

For small groups we feel that this method is effective in sustaining interest and at the same time teaching the subject matter. However, it would be well for anyone who likes to lecture and expects to do most of the talking to leave this method alone.

In our better seed programs we probably have been guilty of forgetting that the folks who can do us much good in disseminating information on cultural practices and varieties are the seed dealers themselves.

For several years in Huron County a chain of elevators has been working with the county agricultural agent and certified seed growers in distributing to their patrons good seed beans and barley. The elevator management is sold on the idea that the commercial grain which the farmers bring in will be no better than the seed which they sow. This fall the county agricultural agent and crop specialist met with managers of another chain of elevators in the same section of the state and within a few years they will be proceeding in the same manner as the company previously mentioned. The county agricultural agents of most counties are in a position to get their seed and fertilizer dealers working together upon a definite program and the extension agronomist should encourage and assist him in doing this work.

In summary, we have found in Michigan that the aids to effective extension work are both material and human. The use of objective tests as a basis for discussion, field demonstrations with schools, employing of pictures, and occasionally charts at indoor meetings might be classed as material aids. Smith-Hughes instructors, in cooperation with the county agricultural agents, and seed dealers can be the human aids that can make our work more thorough.

Extension work, and particularly agronomy extension which must consider soil and climatic problems, presents a challenge which is hardly found in any other type of teaching. We should make use of all assistance possible in meeting this situation and in carrying to our farmers the best information available

EXTENSION METHODS[1]

D. L. Gross[2]

EXTENSION methods have changed greatly in the past 20 years. Certain methods, applicable today, could not have been used in the formative period of our extension program. The changed attitude of both farm and city people towards the extension service has made possible the use of new methods of approach. In the earlier years, scepticism toward so-called "book farming" was widespread. Cooperators were few and far between. Opposition was open and militant. We have a photograph in Nebraska which illustrates this attitude. It was taken in 1920 in Clay County. It shows one of our county agents posed before a sign which stood at the gateway of a farmstead. It read as follows: "Every tenth agent will be shot Nine have already been here "

Although this sign was not posted particularly for the edification of county agricultural agents, it did more or less symbolize the feeling of the times toward the extension service Extension workers found themselves on an uncharted sea with a somewhat uncertain compass. The county agricultural agent, in order to establish himself in his community, necessarily devoted the major portion of his time to personal service work His annual report listed the number of hogs vaccinated, chickens culled, trees pruned, and bushels of seed treated.

We may today look upon these methods as outmoded, yet it was through this approach that farm people came to visualize the need and the value of an extension program Without this initial step the acceptance of the program would have been greatly delayed.

Today we try to avoid personal service and predicate our program upon organization, leadership training, and group action We can do this today only because of the foundations built in the past We can do it because of the changed attitude of the people, and because we command their respect and confidence We can do it because farm and city folk alike appreciate the experiment stations, the colleges of agriculture, and the extension service for assistance and guidance given in the solution of their problems Today we are sometimes overwhelmed by the faith evidenced in our recommendations. Dr. R. D. Lewis made this significant statement before this Society last winter (Jour. Amer. Soc. Agron., 30:180): "It was only a few years ago that we often wondered if anyone would accept our recommendations. Now we must ever think of the results of large groups accepting them." With this changed attitude of the general public and particularly of farm people, the extension service is enabled to carry out a much broader and more effective program.

WORKING WITH GROUPS

Although the extension worker recognizes that his program must be

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seasoned with a measure of personal service, he realizes also that his major activities must be with groups if his program is to reach the greatest number, and if it is to attain the desired ends. Such groups may be of many types. They may be simply unorganized farm community educational meetings of the lecture or discussion type, or they may involve result or method demonstrations On the other hand, they may be organized groups and involve town as well as farm people. The tendency at the present time is to work more and more with the latter type Unorganized groups have no crystallized purpose. They make no plans, delegate no authority, and accomplishments are dependent upon the independent activity of individuals. Organized groups have a definite purpose They formulate programs, determine goals, and delegate activities Such groups, if properly organized or approached, may become an integral part of an extension program. No extension worker can accomplish much by his individual action alone. By inculcating segments of his program into that of organized groups, however, his efforts are greatly multiplied

One of the outstanding examples of effective group action and yet at the same time one of the simplest is the 4-H Club movement Here an organization is set up for a definite purpose. Authority and responsibility are delegated to leaders. By this means the efforts of a single county extension worker are multiplied many fold His teachings are being carried on in an organized way in many communities with a minimum of direct supervision by himself. In a broader way he makes use of other groups. He organizes communities which plan their own programs, select project leaders, appoint committees, and delegate individuals to perform special missions for the group as a whole. Here again the extension worker has created mechanisms which multiply his efforts and which continue to function so long as he keeps them supplied with necessary inspiration. Other types of county groups could be mentioned such as women's clubs, county soil conservation associations, county poultry, dairy, livestock, or crops improvement associations. Not all of these can be made to function in all counties Unless the inspiration is present to insure continued vitality in such groups, their organization may be detrimental to the program rather than beneficial. Organization of new groups whose activities tend to overlap those already in existence is also unwise. On the other hand, groups already organized for purposes not directly related to extension work are often anxious to inculcate certain phases of the extension program into their own. If approached in the proper spirit, such groups are more than willing to take part in extension programs.

It is in this field that the state extension worker finds his greatest opportunity from the standpoint of group action. He works through organizations which have state-wide or other major interests. Some of these may have a direct interest in agriculture while with others this interest may be indirect only. Reference is made in part to livestock, dairy, poultry, and crop improvement associations. These associations have a direct interest in agricultural problems. To this category might be added some of the federal agencies, particularly the Soil Conservation Service, Smith-Hughes teaching, Farm Security,

and the AAA. In addition, there are insurance firms, farm management companies, and loan agencies which are confronted with many farm management problems. All of these agencies turn naturally to the college of agriculture for assistance. Mention might also be made of civic groups which have state-wide or sectional interests. Newspapers and farm magazines also play an important part in the agricultural field. In some states the state departments of agriculture have certain activities which deal directly or indirectly with farm people.

Wherever the activities of any of these or other agencies deal with farm people, it is important that their programs be correlated closely with that of the extension service. Diverse recommendations as to practices or procedures can only breed lack of confidence in the programs of all groups. Not only is it important, therefore, that there be complete coordination so far as this is possible, but at the same time such correlation will add strength to all programs. Particularly is this true of the extension program. Essentially, many of the problems encountered by these agencies are also those of the extension service. If coordination can be effected, the extension service has in effect gained that many more arms to carry out its aims

COORDINATION

Nebraska has made an attempt to bring about this coordination. Undoubtedly there are many states where a program of integration has developed to greater extent than in Nebraska. It may be of interest, however, to describe briefly a few of the processes that are under way with the hope that some of the ideas may be suggestive to others. Work with each agency will be discussed separately.

State improvement associations or societies.- In Nebraska the Crop, Livestock, Dairy, and Poultry Improvement Associations and the Horticulture Society are supported partly by dues and fees and partly by small state appropriations. In most instances the extension specialist whose interests lie in each of the separate fields is secretary of the particular association. Thus the program of each extension specialist and that of the association he represents are worked out on a coordinated basis. "Organized Agriculture Week," called "Farmers Week" or "Farm and Home Week" in some states, is essentially a meeting time for all of these and other state agricultural organizations. Each presents its own program for the farmers of the state, the meetings being held at the College of Agriculture during the winter months. The secretaries are largely responsible for the formulation of the programs for these meetings. General programs which carry on throughout the year are formulated by a board of directors for each association. The secretaries are members of their respective boards of directors. The programs of these associations consist principally of the sponsorship of projects which are or become part of the extension program of each specialist. As an example, the Nebraska Crop Growers' Association sponsors and finances seed certification and employs a field inspector who acts, with the cooperation of the extension agronomist, as certification manager. The inspector offices

with the extension agronomist. Procedures are set up by the board of directors subject to the approval of a state certification committee composed of members of the College staff. This committee is appointed by the Dean of the College under provisions of the state certification law.

This Association also sponsors other projects by contribution of funds. At present these are as follows: 4-H and College grain judging teams; pasture-forage-livestock program; state and national exhibits; participation in International Crop Improvement Association affairs; publication of an annual report bearing principally on subject matter material; seed lists, and educational circulars.

State department of agriculture.—Three men are employed by the State Department of Agriculture to carry out educational and organization work in the eradication of noxious weeds under the noxious weeds district law Each of the men employed was approved for appointment by the Department of Agronomy. The program of these men is worked out cooperatively with the extension agronomists. Publications are handled in the same manner. Routing of the state department men for educational meetings is handled by the extension service through county agricultural agents The groundwork leading to the organization of noxious weed districts is worked out on a cooperative basis with the extension service. Organization details are handled entirely by the state department men Thus, an important segment of the agronomy extension program has been greatly expanded by new funds and the addition of competent, well-trained personnel

Soil Conservation Service.—Arrangements were made in Nebraska for the state coordinator of the Soil Conservation Service to office in the same building as the extension agronomists. The extension conservationist offices with the extension agronomist Plans for all educational activities are worked out cooperatively between the two services. Technicians of the Soil Conservation Service assist with many of the educational meetings, conservation tours, level schools, etc. Circulars, film strips, motion pictures, and exhibits are prepared cooperatively. It is said that familiarity breeds contempt. In this instance it would seem that a better statement would be, "Close association breeds understanding and a cooperative spirit." The extension program as well as that of the Soil Conservation Service has been strengthened by this unification of approach to the people.

Mortgage Bankers Association.— Firms represented in this Association own much farm land in Nebraska. They employ many agents who act as land appraisors or farm managers or who have duties which bring them in contact with farm problems. They have the management of many tenant-operated farms and thus have much influence in the determination of practices used. Each year the College sponsors a two-day short course for representatives of this Association. Ordinarily, this comprises a one-day field trip and a discussion program at which farm management and valuation problems generally are considered. The extension service takes an active part in the formulation and presentation of these programs. Thus, new emissaries of the extension program are created.

The Nebraska Lumberman's Association.—Each year the extension engineers conduct a series of demonstration schools for the lumbermen of the state. Design and detailed construction methods of approved types of small and major farm buildings are discussed and demonstrated. As a result of this work, lumbermen are in a better position to advise with farmers in their building problems. Enterprising lumbermen in many instances proceeded to build approved types of small farrowing and brooder houses in quantity thus reducing construction costs. A sales campaign placed many thousand of these buildings on farms, thus contributing to the success of the "Hog Lot and Poultry Sanitation" projects of the extension service.

Civic groups. The Omaha Chamber of Commerce and the United South Platte Chambers of Commerce are cooperating in the promotion of the "Pasture-Forage-Livestock" project of the extension service. The Omaha Chamber provides funds which are used for printing circulars and for transportation of farmers to a pasture clinic in November. This is held in Omaha where about 400 attend each year Entries in the program are made by the farmers in the spring of the year. Records are kept by the farmers of their pasture, forage, and livestock projects, and on the basis of these records certain individuals are singled out for special recognition. The clinic is followed by a banquet given by the Omaha Chamber at which prizes are awarded.

The United South Platte Chambers of Commerce aside from actively promoting the project in their respective communities also provide funds for a clinic and a banquet at a convenient point For the state as a whole, from 800 to 1,200 farmers enter this project each year. This program, considering its present scope, could not have been carried out without the aid of these groups More will be said of this program later.

Newspapers and magazines. In cooperation with the Omaha WORLD HERALD, one of the leading daily newspapers in the state, arrangements were made for the publication of a series of Sunday feature articles prepared by members of the extension staff. These covered all the major farm projects of the extension service. After the series was completed, all articles were published together in pamphlet form. 40,000 copies of this pamphlet were printed and distributed to subscribers and through the offices of county agricultural agents and business firms.

Assistance is given by extension specialists to the NEBRASKA FARMER and other farm magazines in the preparation of material for special feature issues.

The Nebraska Farmer's Mutual Fire Insurance JOURNAL, published monthly, and reaching many thousands of farmers within the state, has used its columns for the publication in full of some of our extension circulars.

Several extension news stories clear through the office of the extension editor each day, going to both daily and country weekly papers. Stories for country weeklies clear through the offices of county agricultural agents where they are localized before publication.

CORRELATION OF PROJECTS

Another aspect of extension methods has to do with the correlation of the work between the various subject matter specialists. In some instances there are overlapping or complementary projects which need to be worked out together. When an instance of this kind occurs, a cooperative project may be arranged This has been done in many states. A few illustrations from Nebraska will be outlined briefly.

Pasture-forage-livestock project. - The drouth years in Nebraska not only destroyed or seriously damaged many of the pastures and much of the range land of the state, but they also resulted in greatly reduced livestock numbers in many sections. Grain and hay were scarce and high in price Range land needed rest. Dry subsoils, extreme heat, and swarms of grasshoppers prevented the establishment of new pastures. These problems could not be attacked effectively by any single specialist, nor could they be handled most effectively by several specialists working independently. The situation required the cooperative efforts of all who could make a contribution. The extension service alone, because of limitation of funds and personnel, could not cope with the problem adequately. With this in view, conferences were held at which all interested specialists and representatives of a number of outside agencies discussed the problems and formulated a program. Each individual or agency was assigned its contribution. A state-wide educational program was the first step, involving recommendations for resting permanent pastures, planting temporary pastures, a greatly increased acreage of drought-resisting forage and grain sorghums, the use of silage for both winter and summer feed, the building of trench silos, and special recognition to individual farmers for outstanding accomplishment. Animal husbandrymen, dairy men, engineers, agronomists, and farm management specialists from both the College and extension staff were drafted for educational meetings. As many as six teams of two men each were in the field at the same time. Three to five meetings were held each day by each team for a period of three weeks. Daytime meetings were held on farms where a trench silo could be shown. One member of the team discussed crops and harvesting and ensiling methods. The other discussed feeding practices and trench silo construction. Meetings were held in all counties where the feed situation was acute.

This project is still in operation. As has been already stated, important contributions are being made by outside agencies which have taken a special interest in the program. In addition to those mentioned, the Nebraska Crop Growers' Association and the Nebraska Livestock Improvement Association made substantial contributions of funds. The success of the project is evident at the present time. Where few silos existed in 1935, now there are few farms without them in the general farming area. The acreage of drouth and grasshopper resistant forage and grain sorghums has increased nearly 10 fold. Livestock is better fed and numbers are increasing. An extra trench of silage carried in reserve can be found on many farms. This project has developed into an outstanding example of the effectiveness of whole-hearted cooperative effort.

Irrigation schools.--The drouth years in Nebraska greatly stimulated interest in irrigation. Three new canal projects have been developed and hundreds of new pump projects have been installed by individual farmers. It is estimated that by 1940, land under irrigation in Nebraska will have been increased by one-half million acres over that of 1934. Many hundred farmers without previous irrigation experience are already being confronted with irrigation problems with which they are not familiar. To meet this problem, a series of irrigation schools was organized by the extension engineers. Realizing that many of the problems involved were agronomic, the extension agronomists were called upon for assistance in conducting these schools. The groups in attendance at these schools were mostly young men between the ages of 20 and 35 Three to five one-day sessions were held with each group Lessons included (1) use of the farm level; (2) land preparation, including location of canals and field arrangement; (3) use of water; (4) cropping and rotation practices; and (5) special soil problems. Where there was interest in pump irrigation, one lesson was given dealing with wells, pumps, power equipment, etc. These schools have already prevented many costly mistakes and have set up in each of the communities effected a group of men who can be of service to their neighbors in the solution of both engineering and agronomic problems An expansion of this program is planned for 1939

Other joint projects Several other joint projects might be listed, important among these being the following.

1. Home beautification project. Cooperating specialists: Extension specialists in home management, extension engineer, extension forester, extension horticulturist This work is carried on through women's delegate groups representing county women's clubs. The husbands of these women also attend

2 Sewing machine clinics. Cooperating specialists: Extension clothing specialists and extension engineer Carried out as in (1) above.

3. Poultry and hog lot sanitation projects Cooperating specialists: Extension animal husbandry, poultry, agronomy, and engineering specialists. Carried out by demonstration meetings.

DEVELOPMENT OF LEADERSHIP

A discussion of extension methods would not be complete without due consideration being given to leadership development. Present-day extension work is built on the principle of local leadership. Without it our programs would collapse. It is important, therefore, that we weave into all our project planning, methods which will develop leadership.

The AAA program has given us a remarkable demonstration in leadership development. It has given us a new conception of the volume of latent leadership. It has uncovered leadership where we thought none existed. It has developed leadership which is now taking an active part in our extension program as well as in other fields. The more intimate contact of this leadership with the extension

service has in most instances changed the attitude of individuals from that of doubt or even open opposition to one of faith in and whole-hearted cooperation with the extension program. This augmented leadership has made it possible for the extension service to extend its program directly to a group of people who in the past have been served but indirectly.

The germ of leadership is instilled first of all by recognition of the individual, whether it be by election or appointment to an office, assignment of tasks, or public recognition for special accomplishment.

Not all individuals will respond to these stimuli. Not all are capable of leadership. Whether or not the individual responds, he has received much personal benefit. Of interest in this respect is a short paragraph in the August 1938 issue of the READERS DIGEST. This paragraph was headed, "The Tonic of Praise." It read as follows: "Praise is not only gratifying—it is the source of fresh energy which can be measured in the laboratory. Dr. Henry H. Goddard, in his years at the Vineland Training School in New Jersey, used the 'ergograph,' an instrument to measure fatigue. When an assistant said to a tired child at the instrument, 'You're doing fine, John,' the boy's energy-curve soared. Discouragement and fault-finding were found to have a measurable opposite effect."

In Nebraska we have certain projects or project phases into which have been inculcated features or methods which have for their purpose the development of leadership, the energizing of individuals to continue with and improve a good piece of work, or to stimulate larger numbers to follow the example of those who are recognized as leaders. These projects or procedures will be outlined briefly.

Recognition for soil conservation.—In Nebraska, as in other states, there are many farmers who have done outstanding work in the maintenance of soil fertility and in the control of erosion. In cooperation with county soil conservation associations, 13 of which are organized in the state, the extension agronomist and conservationist made arrangements for special achievement meetings in 10 counties. These were sponsored locally by the directors of the soil conservation associations, the Soil Conservation Service, and the county farm bureaus. From 5 to 12 farmers who merited recognition for outstanding accomplishment in soil conservation on their farms were selected in each county by committees of the above organizations. Association funds were used to purchase 16-mm colored motion picture film. One hundred to 200 feet of film were used in each county. Pictures were taken of the selected farmers and their families, their farmsteads and livestock, and the various phases of soil conservation work under way on their farms. County and statewide publicity was given as to the time, place, and nature of the achievement meetings. These were held in the evening during the winter months. In most instances the meetings were preceded by a meal for which a small charge was made. In counties where an evening meal was not served, lunch was provided at the close of the meeting. The serving of a meal or lunch at gatherings of this kind is deemed to be of considerable importance. It tends to break down barriers and promotes a feeling of good fellow-

ship. The evening program usually started with entertainment numbers These were followed by a brief discussion by the president of the association and presentation by him of "Certificates of Achievement" to those selected. The outstanding accomplishments of each recipient were outlined briefly as the certificates were presented. Each certificate bore the signatures of the officers of the association. The certificates were of special design showing cuts of present day conservation methods. The same certificate form was used in all counties, each association paying for the copies used locally. With each presentation the recipient was given an opportunity to reply and to discuss his conservation methods. There probably will be no disagreement with the statement that the remarks of these men were tremendously more influential than one could expect from similar though perhaps more carefully phrased remarks of a specialist.

Following the presentation of certificates, the motion pictures taken locally were shown first and were followed by those taken in other counties The extension conservationist interpreted the pictures as shown The program ended with short remarks by other officers of the association and by representatives of the extension service and the Soil Conservation Service In some instances those honored were later feted by local civic clubs. The success of these meetings makes it certain that this project will be continued from year to year by the local associations

Pasture-forage-livestock project This project has been discussed from the standpoint of cooperative group action It lends itself also, however, to leadership development Thirty to 40 farmers are given special recognition each year for outstanding accomplishment in farm management, with respect to pasture management, feed supplies, and livestock enterprise By publicly recognizing their accomplishments, and by using their farms as community demonstrations, these men are encouraged to carry on and improve their practices

Level schools. Interest in contour farming has increased greatly since the organization of the Soil Conservation Service Many farmers were asking the extension service for assistance in running contour lines. The number of requests was such that they could not be taken care of by county agricultural agents or state extension workers The extension conservationist, in cooperation with the extension engineers and the Soil Conservation Service, accordingly planned a series of level schools to which selected young men ranging in age from 18 to 30 were invited. At these schools particular emphasis was given to the problems of contour farming and how to meet them. Fields were studied from the standpoint of contour operations and, after preliminary instruction, lines were run by the group. From two to five instruments were available, including one homemade level device made from a carpenter's level. Instructions were given for the construction of these. The young men were advised where low-priced instruments could be purchased and the suggestion was given that they might run contour lines for neighbors for a small fee and thus defray part of the purchase price. They were advised to place themselves at the service of their neighbors and thus make themselves useful members of their community. Publicity was given in the local

papers telling of these schools and giving the names of the men who had received instructions. Seventy counties were reached by these schools. Contour lines were run on many farms as the result of this training. The close working relationship between the extension service and the Soil Conservation Service was a vital factor in the success of this project.

Irrigation schools.—This project phase has been discussed in relation to the correlation of the activities of two or more specialists working in related fields. These schools, aside from imparting information, served also to impart the germ of leadership in the minds of the young men who took the training. Local news stories set them apart from their fellows. The training received equipped them to be of service to their neighbors either by actual field assistance or by discussion with individuals or groups.

SUMMARY

This discussion of extension methods is far from complete. Many other items might be included, such as county program planning, leader training or delegate schools, district meetings with county agricultural agents to discuss subject matter material, yearly subject matter handbooks prepared by each specialist to be used by county agricultural agents as handy references, coordination and cooperation with research, office organization, etc. The illustrations given suffice to show how the extension service may so adapt its programs and its projects that they will lend themselves to leadership development, group action, integration of work of all agencies dealing with agricultural problems, and coordination of the efforts of specialists within the extension service. Without these aids the efforts of an individual extension worker cannot be most fruitful.

NOTES

CEREAL NURSERY SEEDERS[1]

THE nursery seeders described herein were designed for seeding rice nursery experiments at the Texas Agricultural Substation No. 4, Beaumont, Tex.

ADJUSTABLE SEEDER

It is desirable to have a readily adjustable nursery seeder in order that all varieties within a given experiment may be sown at approximately the same rate owing to the wide variation in weight per bushel of different varieties of rice This was accomplished by mounting a

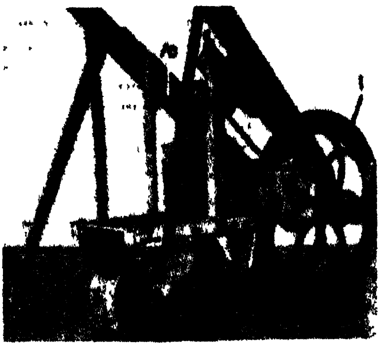

FIG. 1.--Adjustable seeder. (1) Drive wheel, 17 inches in diameter, (2) frame 25 inches long made of 1-inch angle iron; (3) Planet Junior press wheels, 7 inches in diameter, (4) Planet Junior K312 furrow opener, (5) $\frac{5}{8}$-inch rectangular bar welded to furrow opener, (6) harrow bar 7½ inches long; furrow opener is attached to bar with harrow tooth clamp, (7) sheet metal grain spout; (8) fluted feed, from Hoosier one-horse grain drill made from 1897 to 1911; (9) sheet metal pan for retaining excess grain; (10) removable pin to allow operator to tip fluted feed forward for emptying excess seed which falls into pan.

FIG. 2.—Fluted feed showing method of adjusting and cleaning. (1) Feed cup made of heavy gauge sheet metal; (2) feed roll; (3) $\frac{3}{4}$-inch angle iron attached to sides of fluted feed assembly with small stove bolts; (4) 11-tooth sprocket; (5) No. 25 drive chain (6-tooth sprocket on drive wheel); (6) oil holes for bearings (7); (8) knob for adjusting rate of seeding; (9) slot marker on adjusting rod; (10) removable pin to enable operator to tilt fluted feed forward for cleaning.

small fluted feed, from an ordinary grain drill, upon a specially constructed angle iron frame as shown in Fig. 1.

The weight per bushel of the rough rice was found to be one of the most important factors governing the rate at which the seed flowed

[1]Joint contribution of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Texas Agricultural Substation No. 4, Beaumont, Tex.

through the fluted feed. A chart based on a large number of trials was computed to show the settings necessary to sow approximately uniform weights of seed per row for varieties varying in test weight from 35 to 52 pounds. As shown in Fig. 2, the fluted feed is adjusted by

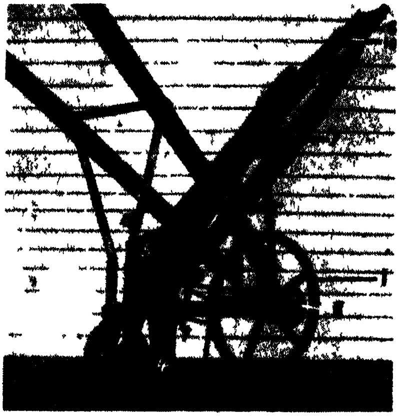

FIG. 3.—Nursery space seeder. (1) Drive wheel, 17 inches in diameter; (2) frame, strap iron 21 inches long; (3) press wheel; (4) Planet Junior K312 furrow opener; (5) sheet metal grain spout; (6) frame, strap iron 50 inches long; (7) sheet metal trough which is arched slightly in center to keep from bouncing when seeding on rough land; (8) 15-tooth drive sprocket; (9) 7-tooth sprocket; (10) 6-tooth sprocket on upper pin to carry chain.

FIG 4.—Close-up showing seeding mechanism of nursery space seeder (1) Sheet metal trough; (2) seed cup; (3) sheet metal grain spout; (4) drive shaft, galvanized pipe, 7/8 inch in diameter; (5) 6-tooth sprocket; (6) 7-tooth sprocket; (7) 15-tooth drive sprocket; (8) 6-tooth sprocket for tightening drive chain; (9) No. 25 drive chain.

turning a knob attached to a 3/8-inch standard thread bolt. A total of 7¼ revolutions of the knob will correct for a difference of 17 pounds in test weight, or from 35 to 52 pounds per bushel, when seeding at the rate of 90 pounds per acre in rows spaced 1 foot apart. Marks on the rod, shown in Fig. 2, spaced for every two turns allow the setting to be made quickly and accurately

FIG. 5.—Sheet metal cup attached to link of drive chain.

The furrow opener is a K312 Planet Junior plow attached by means of a short piece of harrow bar bolted to the frame of the seeder, as shown in Fig 1. A rectangular bar the size of a harrow tooth was welded to the upper portion of the furrow opener. A harrow tooth clamp attached to the furrow opener holds it in place. The opener can be readily adjusted for seeding at different depths. A sheet metal grain spout is attached on the back of the furrow opener.

A seeder of this type has been used in sowing nursery experiments at Beaumont for 4 years. Uniform stands have been obtained each year, whereas in previous years, when sown by hand, the stands were rather variable.

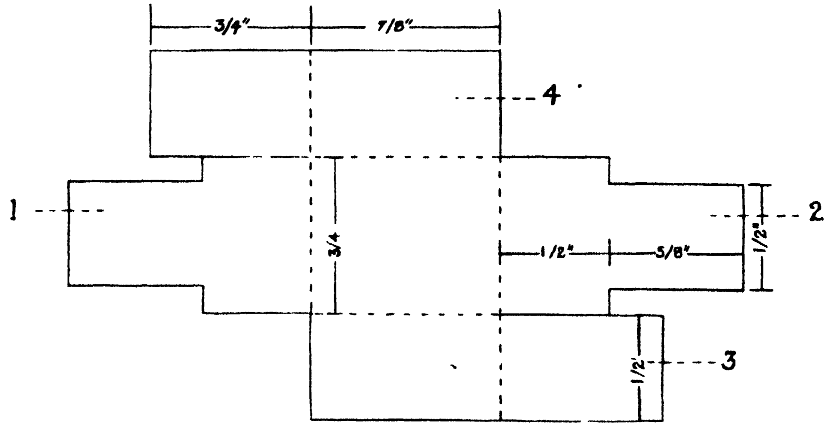

FIG. 6 Diagram showing how cups were made (1 2) Bent down and fastened to chain link. (3, 4) bent up to form sides of cup

FIG. 7.—Rows sown with space seeder.

Each lot of seed was placed in a section of an automobile inner tube before sowing and rubbed thoroughly to remove all stems and beards After rubbing, the dust, stems, and light-weight grains were removed with a laboratory aspirator. This operation materially reduced the variation in bushel weight among different varieties and enabled the grain to flow through the fluted feed at a more uniform rate. A piece of inner tube at least 5 inches in diameter and 2 feet in length was found to be the most satisfactory for cleaning samples that varied from 1 to 2 pounds in weight.

SPACE SEEDER

The space seeder, shown in Fig. 3, consists of small sheet metal cups 7/8 inch by 3/4 inch and 1/2 inch deep attached to each link of a No. 25

cast drive chain, as shown in Fig. 4. The cup shown in Fig. 5 was made from 28 gauge sheet metal cut according to the diagram shown in Fig 6 The speed of the chain to which the cups are attached is so regulated that a seed placed in each cup is dropped every 4 inches. A single seed is dropped in each cup by hand, and any extra seeds dropped accidentally in a cup are removed with forceps. The furrow opener used on this seeder is similar to the one on the adjustable seeder and was attached in the same manner

Two men, one filling the cups and the other pushing the seeder, can sow approximately 450 rod rows in a 9-hour day. With two men filling the cups and a third pushing the seeder, as many as 560 rows were seeded in 9 hours. Plants in rows sown with this seeder are shown in Fig. 7 This type of seeder has been used during 1937 and 1938 and the spacings have been satisfactory The stands have been superior to those obtained from hand seeding in previous years.—H. M. BEACHELL, *Texas Agricultural Substation No 4, Beaumont, Texas.*

PORTABLE FIELD DRIER[1]

IN recent studies on the root reserves of the European bindweed (*Convolvulus arvensis* L), it was necessary to have a drier or dehydrator which could be used in the field Four units have been

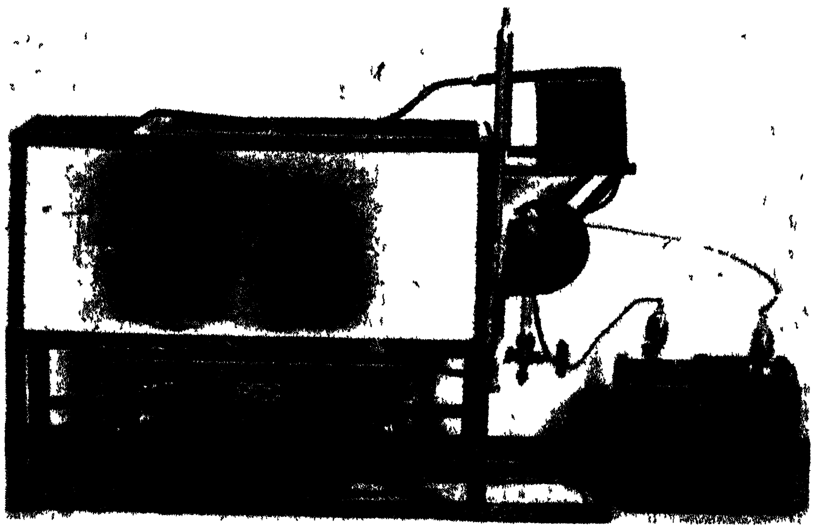

FIG 1 – Portable field dehydrator

assembled and one has been used for the past three seasons. The external appearance of the equipment is shown in Fig. 1, and the internal construction is illustrated in Fig. 2.

[1]Journal Paper No J-618 of the Iowa Agricultural Experiment Station, Project 484, in cooperation with the U S. Dept. of Agriculture

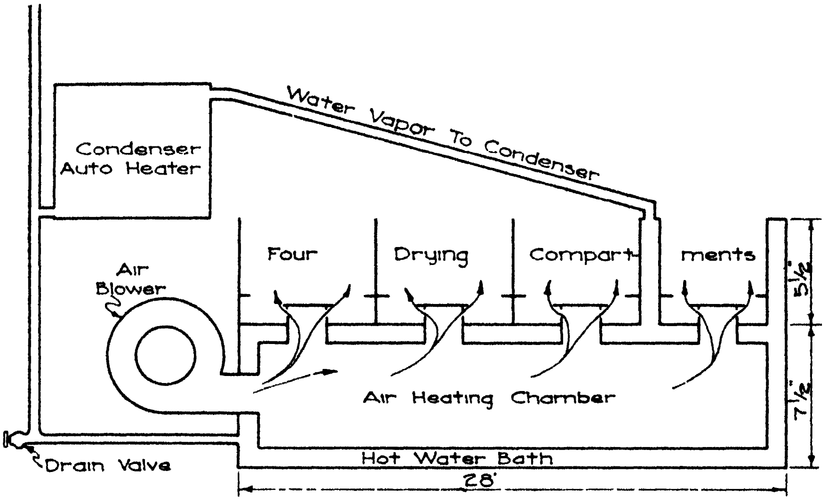

FIG. 2.—Diagrammatic view of the construction of portable field drier.

The external dimensions of the drier in its supporting angle iron frame are $36 \times 9\frac{1}{2} \times 23$ inches The dimensions of the enclosed structure are indicated in Fig. 2. Air from a 6-volt blower enters a compartment heated by a water jacket. Baffles inside of the heating compartment are desirable to prevent air channels. The hot air from the heating compartment is vented into four drying chambers through adjustable vents. The drying compartments are provided with removable screen bottoms and should have at least an inch baffle around the edges to force the air through the center of the sample placed in the compartment. The end compartment is water-jacketed to keep the temperature as high as possible. A steam outlet from this jacket leads to a condenser made from an auto heater. The condensate returns to the water bath through a copper pipe of rather large diameter to facilitate filling and also to serve as blow-off if the bath is overheated. A rubber tube can be placed over the end of this vent and led to the ground to prevent wetting of the samples by escaping water.

The water bath is heated with a portable gasoline camping stove. Some form of shelter or tent is desirable to prevent the wind from blowing out the flame of the stove An asbestos covering around the sides of the tank is desirable to prevent excess radiation. This assembly on an angle iron frame is shown in Fig. 1.

After the drier is in operation and the stove adjusted, the temperatures in the four compartments will be about 80°, 75°, 70°, and 65°, respectively, and will stay practically constant. The sample to be dried (about 200 grams) is placed on a piece of cheesecloth 24 inches square and moved progressively from the hotter drying chamber to the cooler chamber as it dries. If one wishes to stop enzyme action before drying the tissue, the sample may be given a preliminary heating in a separate unit at the temperature of boiling water before being placed in the drier. Root samples having about 80% moisture, such as those used in these studies, will be completely dry in 3 hours.

A standard 6-volt battery will operate the blower for about 90 hours. Continuous service can be maintained with two batteries which are alternately used and charged In hot, still weather one radiator may not offer sufficient condensing surface to prevent loss of water vapor In such a case, a second radiator can be mounted in tandem with the first —R M HIXON AND A L BAKKE, *Iowa State College, Ames, Iowa*

A TOOL FOR THE RAPID SAMPLING OF SOILS

MEN interested in soils frequently have occasion to take composite samples of soils Doing this with a soil auger or spade is at best a rather slow job, especially when a number of samples are taken

In Fig 1 are shown tools that have proved very satisfactory for rapidly taking a number of composite soil samples from cultivated land They consist of a tube for sampling through the A-horizon and a tool for removing the sample The sampling tool was made from an 18-inch piece of plumber's brass tubing with a handle shaped from a piece of wood fitted into one end A slot for facilitating the removal of the soil was cut into one side of the tube with a thin emery wheel and a hack saw blade The bottom end of the tube can be kept sharpened with a large-size cork borer sharpener or mill file

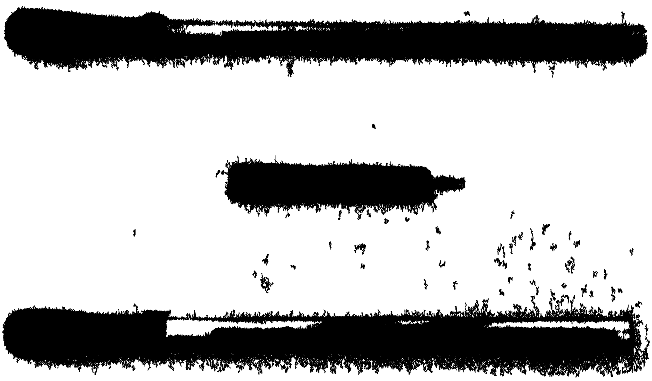

FIG 1

Since the brass tubing is made in a number of diameters, a size of tube that will provide the desired quantity of sample from a given number of borings can be chosen An ordinary screw driver can be used for removing the sample Shown in Fig 1 is one on which the handle was extended almost the full length of the shank to make it less tiresome to use

Using the small tube and screw driver shown in Fig 1, one operator can readily take as many as 50 composite samples consisting of 20 borings each in a day —FRANKLIN L DAVIS, *Louisiana Agricultural Experiment Station, University, La*

A METHOD FOR OBTAINING A CONTINUOUS MEASUREMENT OF SOIL MOISTURE UNDER FIELD CONDITIONS

A METHOD has been devised for making *in situ* under field conditions a continuous measurement of soil moisture. It consists of imbedding in the soil a standardized block of $CaSO_4$ (plaster of paris). The moisture content of this material varies directly with that of the soil. Since the dielectric constant of plaster of paris is proportional to its moisture content, a measure of the conductivity of the block is a measure of soil moisture. Conductivity determinations are easily made by means of electrodes and a form of the Wheatstone bridge.

This device measures soil moisture ranging from the wilting point to the field capacity or it is really a measure of the available water It denotes the wilting point accurately. By knowing the wilting point and the available water, the total water content is thereby also known. The method possesses a surprisingly high degree of accuracy.

G. J Bouyoucos and A. H Mick, *Michigan Agricultural Experiment Station, East Lansing, Mich*

AGRONOMIC AFFAIRS

SOME ACTIVITIES OF THE DIVISION OF BIOLOGY AND AGRICULTURE OF THE NATIONAL RESEARCH COUNCIL

THE following brief summary of certain activities of the Division of Biology and Agriculture, National Research Council, is based upon the 1937-1938 annual report of the Chairman, Dr R E. Coker, and from supplemental information obtained from him relative to development since July 1, 1938

INTERDIVISIONAL COMMITTEE ON AEROBIOLOGY

Dr E C Stakman has been named chairman, to succeed the late Dr. Fred C. Meier who, with Dr E B. McKinley and others, was lost with the ill-fated Hawaiian Clipper, while on an official flight in the interest of aerobiology. The Carnegie Corporation of New York has made available for future use of the Committee the balance of some \$2,400 remaining from the Meier grant

COMMITTEE ON ECOLOGY OF GRASSLANDS IN NORTH AMERICA

This committee, of which Dr. V E. Shelford is chairman, is sponsoring a movement to set aside more or less extensive grassland areas and preserve them for research and as controls against ordinary methods of utilization in connection with agricultural and other developments of civilization. Reports growing out of the work of the committee emphasize the necessity for reserving grassland areas comparable in extent and purpose to existing reservations of forest areas in national parks. These reports also list and discuss the kinds of studies of plants and animals, of their interrelations and of their relationships to soils, climate, etc., which might be made possible and be promoted by the reservation of appropriate areas. Two papers have appeared in recent issues of the SCIENTIFIC MONTHLY, *viz.*, "The Need for Research on Grasslands," by Herbert C. Hanson and C. T. Vorhies, March 1938; and "Check-Areas as Controls in Land Use," by Herbert C. Hanson, February 1939.

COMMITTEE ON FORESTRY

The Committee on Forestry, of which Dr. Raphael Zon is chairman, has just completed the manuscript of what seems to be a monumental bibliography of forestry in North America up to 1930. The committee has also completed a report on "Forest Research in the United States."

THE NAPLES ZOOLOGICAL STATION

The National Research Council Table in the Naples Zoological Station is available to one or more qualified Americans who may be interested in availing themselves of the facilities of that station during the ensuing year. A notice regarding the table was published in SCIENCE for May 20, 1938. Application should be directed to the office of the Division of Biology and Agriculture, National Research Council, Washington, D. C.—P. V. CARDON, *representing the American Society of Agronomy and the National Research Council.*

THE NEW AUTHOR AND SUBJECT INDEX

THE cumulative author and subject Index to Volumes 21 to 30, inclusive, 1929–1938, of the JOURNAL is now ready for distribution. It makes 83 pages and is paper covered. The new Index is nearly double the size of the Index to the first twenty volumes of the JOURNAL, published in 1929, a few copies of which are still available.

The new Index will be sold at $1.00 per copy to cover the cost of publication and handling charges.

NEWS ITEMS

DOCTOR EDMUND C. SHOREY died in Washington, D. C., on January 30, following a long illness. Dr. Shorey was a native of Canada and received his training at Queens University, Kingston, Ontario. At the time of his retirement in 1935 and for many years prior to that date he was associated with the Division of Soil Fertility Investigations of the U. S. Dept. of Agriculture.

THE CANADIAN SEED GROWERS' ASSOCIATION will hold its 1939 meeting in Victoria, British Columbia, June 14 to 16. The President of the Association is F. W. Townley-Smith of Lashburn, Sask , and the Secretary-Treasurer, W. T. G. Wiener of Ottawa, Ontario.

ERRATUM

CORRECTIONS are called for in two of the formulae appearing in the article on "The Analysis of Variance with Special Reference to Data Expressed as Percentages", by Andrew Clark and Warren H. Leonard on pages 55 to 66, inclusive, of the January 1939 number of this JOURNAL. The second formula on page 58 should read

$$t=\log\frac{p}{1-p}.$$

On page 59, the expression in the third paragraph should be written as follows: $\frac{S(n_r-1)\ (V_r-V)^2}{2V^2}$.

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GENETICS OF BARLEY[1]

D. W ROBERTSON[2]

OF the cereal crops, barley offers a superior opportunity for genetic studies It is adapted to a wide variety of conditions and shows many different characters. Since all of the cultivated barleys have seven chromosome pairs, they afford an excellent opportunity to study the various character pairs with respect to their linkage groups.

A rather extensive review of the literature on barley genetics was published in mimeographed form by Robertson and Wiebe (17).[3]

In studying the interaction of the various factor pairs, a more difficult problem is found than in the case of cross fertilized crops. Hand pollination of each floret becomes a rather tedious job in order to obtain enough plants to make the backcross data reliable. In most of the studies F_2 data verified in F_3 were used. A few linkages are reported where backcrosses to the F_1 were made. It is not always possible to obtain on the first trial the characters in the proper combinations; however, synthetic parents are being built up as rapidly as possible.

The material reported in this paper will deal with the linkage of characters in the common cultivated barleys, *Hordeum vulgare*, *H. intermedium*, *H. distichum*, and *H. deficiens*, all of which have been reported to have seven haploid chromosomes. A short description of some of the newer characters is given at the end of the paper. It is unfortunate that a complete check of all the known characters is not available. However, a collection of these characters is being made by G. A. Wiebe of the U. S. Dept. of Agriculture, and also by the Colorado Experiment Station. Where possible, all identical characters are being checked and many of those reported by Robertson and Wiebe (17) are available to workers in the field.

To date seven linkage groups, in which two or more characters have been located, have been reported in barley.

GROUP I

Group I contains the two-row versus six-row factor pair (Vv). In

[1]Contributio from the Department of Agronomy, Colorado Agricultural Experiment Sta , Fort Collins, Colo. Also presented at the annual meeting of the Society, November 16, 1938, in Washington, D. C. Received for publication December 9, 1938.

[2]Associate agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 282.

this group the following factor pairs have been located. Toothed versus untoothed lemma was reported by Ubisch, cited by Wexelsen (22), with 16.6% crossing over and by Wexelsen (22) with 15.4% crossing over with (Vv). This character is designated by the letters (Gg) (Robertson and Wiebe).[4] Awned versus awnless (Lk lk) is reported by Kuckuck (9) to be linked with (Vv), the row factor pair, with 9.57% crossing over. Robertson (16) found the factor pair (Pr pr) for purple versus non-purple straw to be linked with (Vv) with 9.8% crossing over.

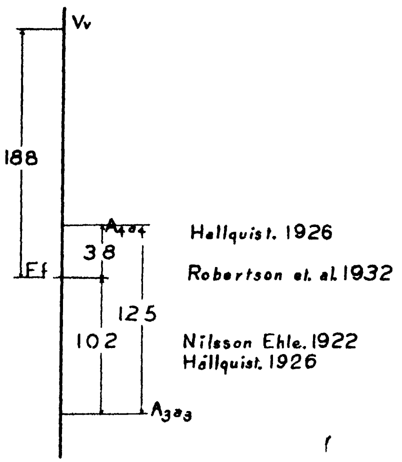

FIG. 1.

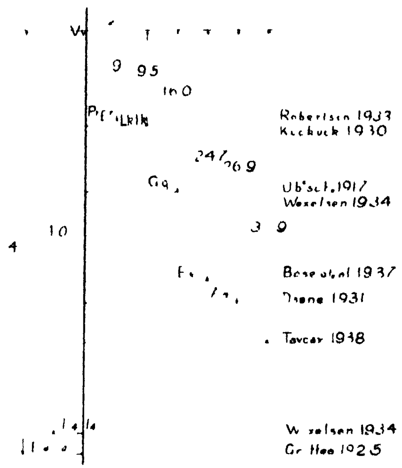

FIG. 2.

Bose, *et al.* (1) have found that a factor pair (Ee) for awns versus no awns on the outer glumes is linked with (Vv), two-row versus six-row, with 24.7% crossing over. The factor pair (Ff) for green versus chlorina seedlings in Minn. 84-7 is located in group I with 18.3% crossing over Two white seedling factor pairs (A_3a_3) and (A_4a_4) described by Hallquist (5) and Nilsson-Ehle (13) are located close to the (Ff) factor pair. Their relationship to the (Vv) factor pair, however, has not been determined. Daane (3) found a green versus white seedling factor pair (Aa) linked with the (Vv) factor pair with 26.9% crossing over. An internode length factor pair (L_4l_4) is reported by Wexelsen (22) to be linked with the (Vv) factor pair with 40.0% crossing over. (See Figs. 1 and 2.)

Buckley (2) studied several color factors affecting the lemma. Fig. 3 presents the location of the following factors on the chromosome map: (P_cp_c) purple versus white veined lemma, (Re re) red versus white pericarp, and (Pp) purple versus white lemma. Tavcar (20) studied the inheritance of a factor pair (Rin rin) for number of rachis internodes and found a linkage between two-row versus six-row and high and low internode number. He calculated graphically a crossover value of 32.94%.

[4]Throughout this paper the symbols suggested by Robertson and Wiebe (17) will be used.

Several other factor pairs are reported as being located in group I, but so far no crossover values have been determined. A factor pair for early versus late heading is located in this group by Griffee (4) and Neatby (12).

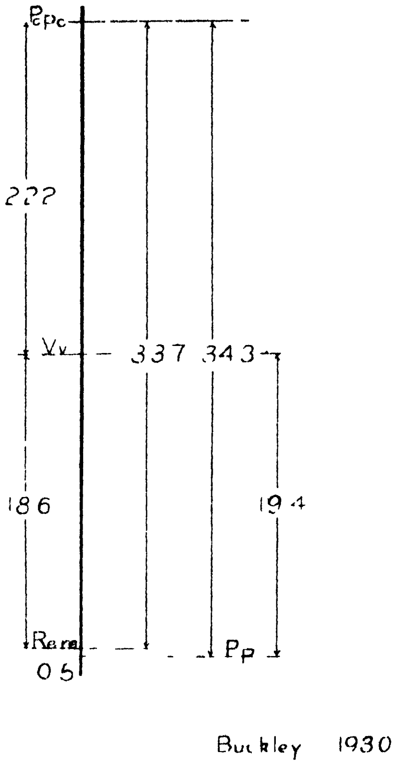

FIG. 3.

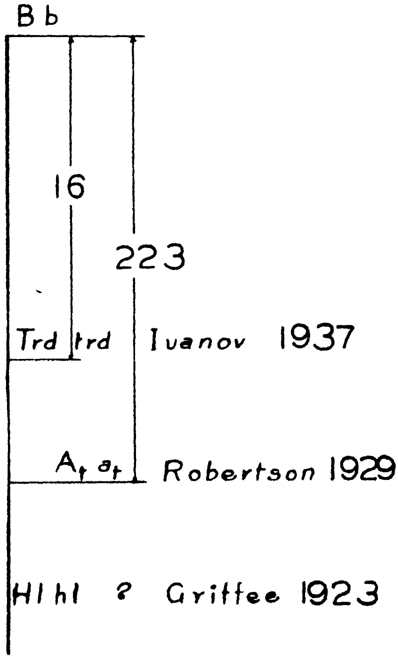

FIG. 4.

GROUP II

Black versus white lemma and pericarp (Bb) is located in group II (Fig. 4). Several other factor pairs are also located in this group. A factor pair ($A_t a_t$) for green versus white seedlings has a crossover value of 22.29%, with the (Bb) factor pair for black versus white lemma and pericarp. Ivanova (8) reports the linkage of a factor pair (Trd trd) for an extra outer glume and the (Bb) factor pair with 15.3 to 16.9% crossing over. The third outer glume behaves as a simple recessive to normal glumes. Griffee (4) found one of the factor pairs (Hl hl) for resistance versus suscep-

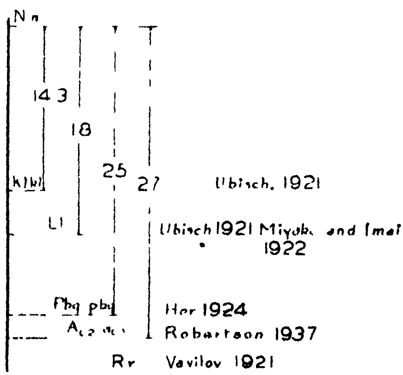

FIG. 5.

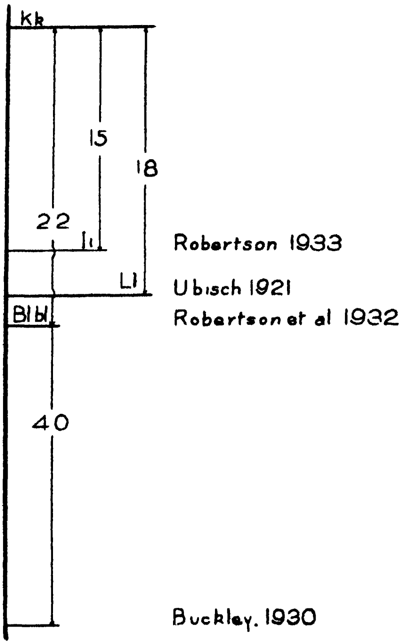

FIG. 6.

tibility to *H. sativum* in this group.

GROUP III

Group III (Fig. 5) contains the factor pair (Nn) for covered versus naked caryopsis. Several factor pairs have been found by various workers in this linkage group. Hooded versus long awned (Kl kl) was found to be linked with covered versus naked with 14 3% crossing over by Ubisch, cited by Daane (3). A factor pair for dense versus lax heads (Ll) was found to be located in this group by Ubisch, cited by Wexelsen (22), and by Miyake and Imai (11) with from 13.0 to 23.0% crossing over with (Nn).

Two different factors for dense versus lax may be present, but further work is necessary before the point can be definitely determined. Hor (6) found general versus restricted pubescense of the outer glumes (Pbg pbg) to be linked with covered versus naked with 23.0 to 27.0% crossing over. A white seedling factor pair ($A_{c2}a_{c2}$) found in Coast II has a crossover value of 27.24±2.04% with covered versus naked (Nn). Vavilov (21) reports a linkage between a factor pair for rough versus smooth awn and the (Nn) factor pair.

GROUP IV

The factor pair (Kk) for hoods versus awns is located in group IV (Fig. 6). Another factor pair for dense versus lax has been placed in this group by Ubisch with from 16.0 to 20.0% crossing over. One of the factor pairs for blue versus white aleurone color has been located in this group by Buckley (2) with 40.6% crossing over and by Robertson, *et al.* (15) with 22.0% crossing over. The factor pair (Ii) for intermedium versus non-intermedium is linked with hoods versus awns with 15.12% crossing over. Wexelsen (22) cited Ubisch who found a factor pair (Ll) for rachis internode length in this group.

GROUP V

Group V (Fig. 7) contains the main factor pair (Rr) for rough versus smooth awns. The long versus short-haired rachilla factor pair (Ss) has been found in this group with from 28.05 to 45.5% crossing over with (Rr). The following workers have found different crossover values: Daane (3), 28.05%; Sigfusson (18), 30.8%; Wexel-

sen (22) 30.0%; Robertson, *et al.* (15), 34.63%; Hor (6), 35.0%; and McGregor (10), 42.7 to 45.5%. A correlation between the factor pairs for branched versus unbranched stigma (Uu) and rough versus smooth awns was found, indicating that some of the factor pairs for stigma branching are located in this group. Griffee found a correlation between resistance versus susceptibility to *H. sativum* and the rough versus smooth awn factor pair. Wexelsen found a linkage between the factor pair (L_2l_2) for long versus short internode and rough versus smooth awn with 10.0% crossing over. Buckley (2) found a linkage of the factor pair (Ss) and a factor pair (Re re) for red versus white pericarp with 34.7% crossing over. The factor pair (Oo) for white versus orange lemma was also found to be linked with the factor pair (Ss) with 39.1% crossing over. A white seedling factor pair (A_ba_b) found in Black Hulless barley was linked with the factor pair (Ss) with 26% crossing over.

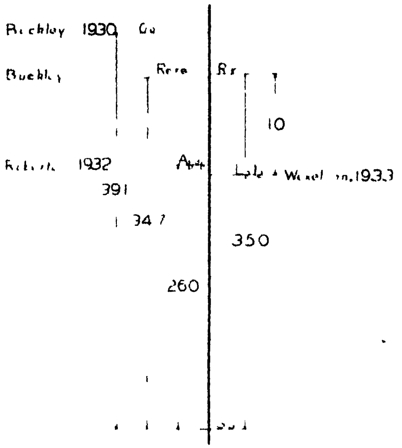

FIG. 7.

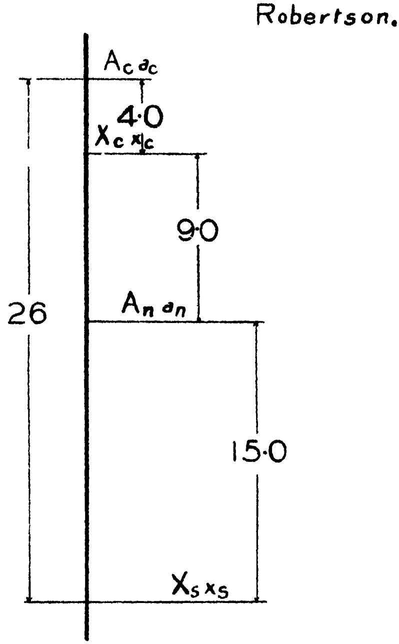

FIG. 8.

GROUP VI

Group VI (Fig. 8) contains several factor pairs for seedling lethals. No mature plant character has yet been found to be linked in this group. The following factor pairs are located in this group. (A_ca_c) for green versus white seedlings in Colsess I, (X_cx_c) for green versus xantha seedlings in Colsess IV, (A_na_n) for green versus white seedlings in Nigrinudum I, and (X_sx_s) for green versus yellow seedlings in Smyrna I.

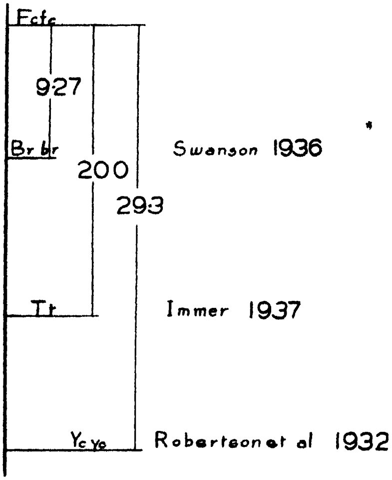

FIG. 9.

GROUP VII

This group (Fig. 9) contains the factor pair (F_cf_c) for green versus chlorina seedlings in Colsess V and the factor pair (Y_cy_c) for green versus virescent seedlings in Coast III. The normal versus brachytic factor pair (Br br) reported by Powers (14) was found by Swanson (19) to be linked with the green versus chlorina factor pair with 9.27% crossing over. A factor pair (Tt) for resistance versus susceptibility to *P. graminis tritici* (Peatland) is reported by Immer (7) to be linked with the green versus chlorina factor pair with 20% crossing over.

DESCRIPTION OF CHARACTERS

A brief discussion of the various characters referred to in the above paper is given below to familiarize workers in barley genetics with them.

1. Six-row versus non-six-row (Vv). Fig. 10. A: (a) six-row, (b) two-row.
2. Toothed versus untoothed veins on the lemma (Gg). Fig. 10. B: (a) toothed, (b) untoothed.
3. Awned versus awnless (Lk lk). Fig. 10. C: (a) awnless, (b) awned.
4. Awns versus no awns on the outer glumes (Ee). Fig. 10. D: (a) awned outer glumes, (b) awnless outer glumes.
5. Green versus chlorina seedlings in Minn. 84–7 (Ff). The seedlings are "cosse green" (Ridgeway Plate V). The plants grow to maturity but are somewhat stunted.
6. Purple versus white veined lemma (P_cp_c). The veins on the lemma are purple in color. This character may fade out at maturity.
7. Red versus white pericarp (Re re). The pericarp color is reddish brown. This character varies considerably and may not be clear cut under all environments.
8. Purple versus white lemma (Pp). The lemma is purple in color.
9. Black versus white lemma and pericarp (Bb). The lemma and palea are black.
10. Normal versus third outer glume (Trd trd). A third outer glume is present. Ivanova (8).
11. Covered versus naked caryopsis (Nn). Fig. 11. E: (a) covered caryopsis, (b) naked caryopsis.
12. Pubescent versus restricted pubescence on outer glume (Pbg pbg). Fig. 11. F: (a) restricted pubescence, (b) pubescent outer glume.
13. Hoods versus awns (Kk). Fig. 11. G: (a) hooded, (b) awned.
14. Blue versus non-blue aleurone (Bl bl). The aleurone color in the absence of red or black pericarp color is blue. Typical non-blue aleurone is found in the

variety Nepal C I 595, blue aleurone in Faust C I 4579 This character shows xenia

FIG 10

15. Intermedium versus non-intermedium (Ii). Fig. 11. H: (a) intermedium (H. dis. nigrinudum), (b) non-intermedium (H. def. nudideficiens), (c) a very extreme type of deficiens.
16. Rough versus smooth awn (Rr). Fig. 12. I: (a) smooth awn, (b) rough awn.
17. Long versus short-haired rachilla. Fig. 12. J: (a) long-haired rachilla, (b) short-haired rachilla.

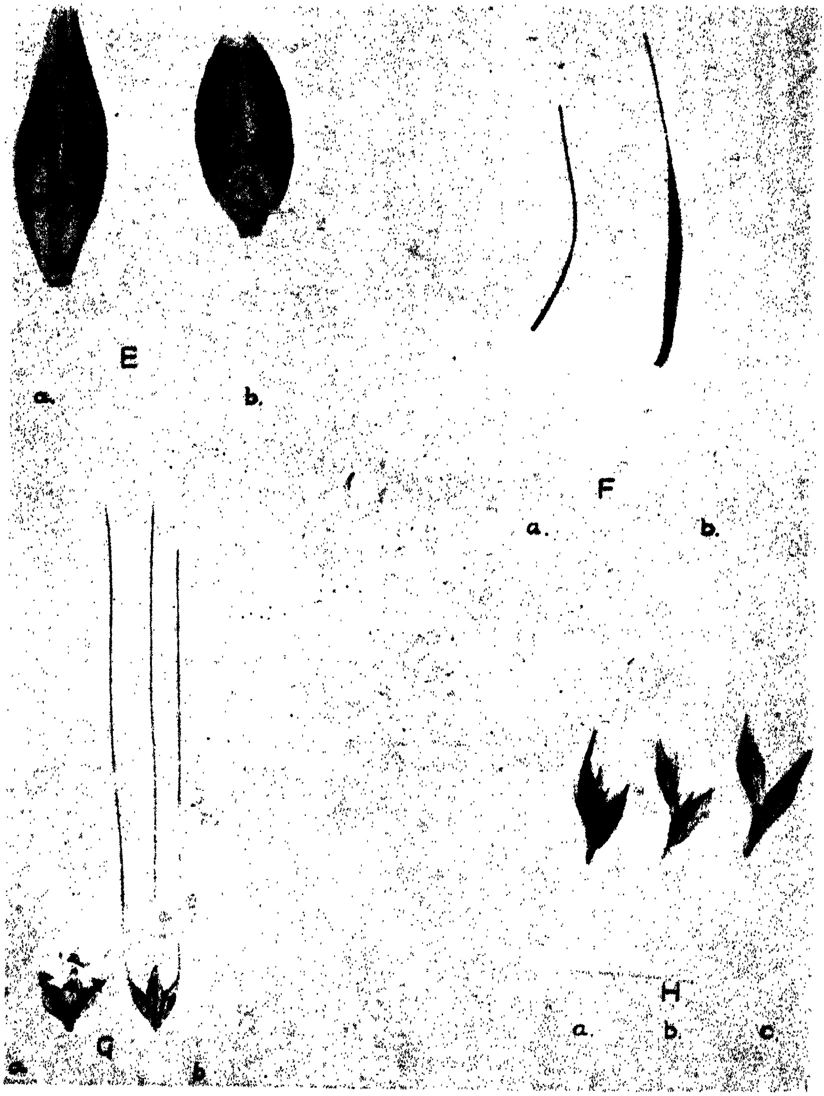

FIG. 11.

18. Branched versus unbranched stigma (Uu). Three factor difference. Fig. 12. K: (a) branched, (b) unbranched.
19. Long versus short internode. Fig. 12. L: (a) Abed Binder (l_3l_3, L_4L_4, L_5L_5), (b) Machine (L_3L_3), (c) Asplund (l_4l_4, l_5l_5).

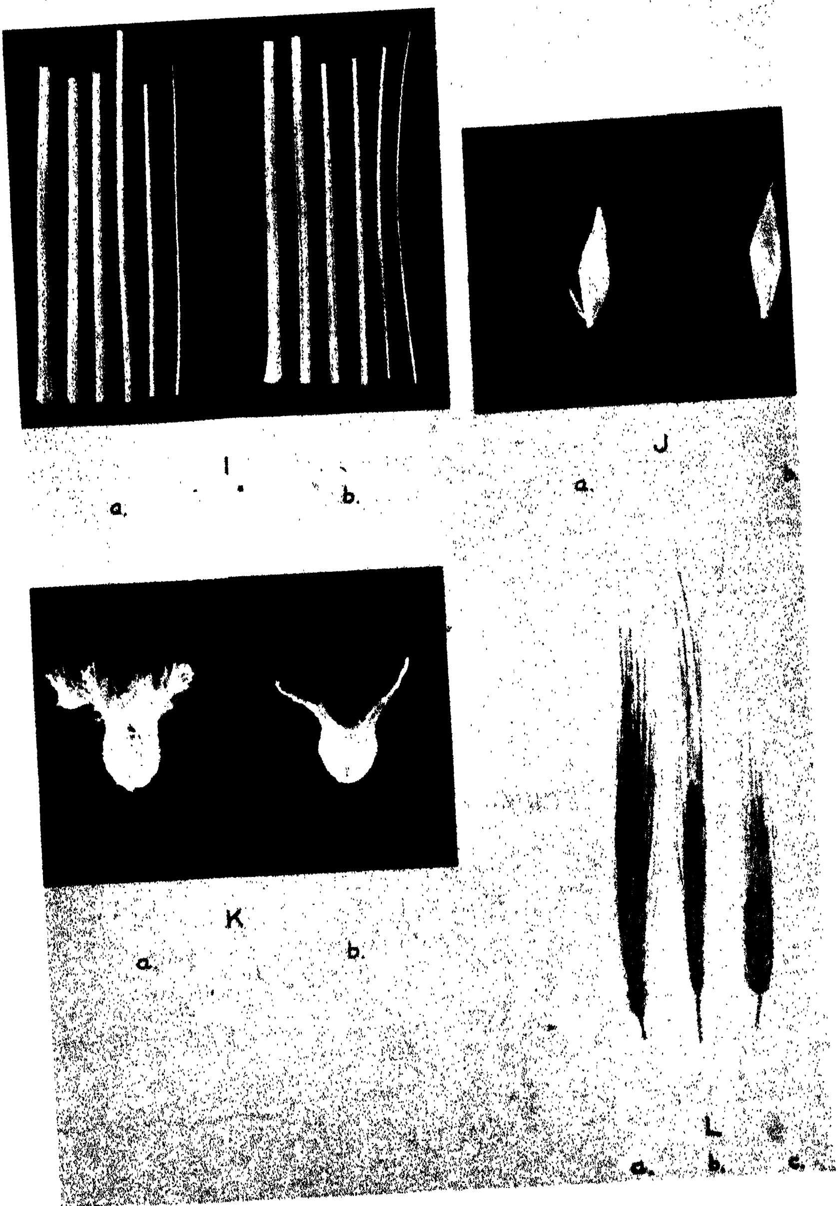

FIG. 12.

20. Green versus white seedlings in Colsess I. The white seedlings die in the seedling stage. The other white seedlings discussed in this paper are similar in appearance to the Colsess I seedling, and die in the seedling stage. They are recessive to normal green.
21. Green versus xantha seedlings in Colsess IV (X_cx_c). The xantha seedlings die in the seedling stage. At high temperatures these seedlings will mature seed. They are "bright chalcedony yellow" (Ridgeway Plate XVII).
22. Green versus yellow seedlings in Smyrna I (X_sx_s). The yellow seedlings die in the seedling stage. They are "citron green". (Ridgeway Plate XXXI).
23. Green versus chlorina seedlings in Colsess V (F_cf_c). The seedlings are "dull green yellow" (Ridgeway Plate XVII). The seedlings grow to maturity.
24. Green versus virescent seedlings in Coast III (Y_cy_c). The first two leaves of the virescent seedlings have green tips. They survive under field conditions at Fort Collins for four or five weeks. The amount of green on the tip of the leaves varies.
25. Normal versus brachytic (Br br). The brachytic plant has shorter nodes than normal plants.
26. Normal versus orange lemma. The lemma is orange colored. The rachis is colored deep orange. This character may be the same as red rachis C. I. 5649.

LITERATURE CITED

1. BOSE, R. D., AZIZ, M. A., and BHATNAGAR, M. P. Studies in Indian barleys. IV. The inheritance of some anatomical characters responsible for lodging and of some ear-head characters in an interspecific cross between two Pusa barleys. Ind. Jour. Agr. Sci., 7:4 88. 1937.
2. BUCKLEY, G. F. N. Inheritance in barley with special reference to the color of caryopsis and lemma. Sci Agr., 10:460-492. 1930.
3. DAANE, A. Linkage relations in barley. Minnesota Agr. Exp. Sta. Tech. Bul. 78. 1931.
4. GRIFFEE, F. Correlated inheritance of botanical characters in barley and manner of reaction to *Helminthosporium sativum*. Jour. Agr. Res., 30:915-935. 1925.
5. HALLQUIST, C. Koppelungen und Synthetische Lethalitat bei den Chlorophyllfactoren der Gerste. Hereditas, 8:229-254. 1926.
6. HOR, K. S. Interrelations of genetic factors in barley. Genetics, 9:151-180. 1924.
7. IMMER, F. R. Rust resistance in Peatland. Correspondence. 1937.
8. IVANOVA, K. V. A new character in barley, "third outer glume," its inheritance and linkage with color of the flowering glumes. Bul. Appl. Bot., Gen. and Plant Breed., Ser. II, Gen., Plant Breed. and Cytol., 7:339-353. 1937.
9. KUCKUCK, VON H. Versuch Einer Vorlaufigen Chromosomentopographie bei Gerste. Der Züchter Hept., 3:68-72. 1930.
10. MCGREGOR, W. G. Inheritance studies in barley. Master's thesis, University of Minnesota. 1929.
11. MIYAKE, K., and IMAI, Y. Genetic studies in barley, I. Bot. Mag., 36:25-38. 1922. (In Japanese. Translation obtained from Dr. G. A. Wiebe.)
12. NEATBY, K. W. An analysis of the inheritance of quantitative characters and linkage in barley. Sci. Agr., 9:701-718. 1929.
13. NILSSON-EHLE, H. Uber Freie Kombination und Koppelung Verscheidener Chlorophyll-Erbeinheiten bei Gerste. Hereditas, 3:191-199. 1922.
14. POWERS, LEROY. The nature of the interaction of genes affecting four quantitative characters in a cross between *Hordeum deficiens* and *vulgare*. Genetics, 21:398-420, 1936.
15. ROBERTSON, D. W., DEMING, G. W., and KOONCE, D. Inheritance in barley. Jour. Agr. Res., 44:445-466. 1932.
16. ——————. Inheritance in barley. Genetics, 18:148-158. 1933.
17. ——————, and WIEBE, G. A. Genetic factors in barley. Mimeographed. 1938.

18. SIGFUSSON, S. J. Correlated inheritance of glume color, barbing of awns, and length of rachilla hairs in barley. Sci. Agr., 9:662-674. 1929.
19. SWANSON, S. P. Genetic and cytological studies on a brachytic mutation in barley. Thesis submitted for the Ph.D. degree, University of Minnesota. 1936.
20. TAVCAR, A. Vererbunghsart der Spindelstufenzahl bei Bastardierungen einiger *distichum* x *vulgare* Wintengersten. Zeit. fur induktive Abstammungsvererbungslehre, 75:106-123. 1938.
21. VAVILOV, N. I. De L'origine d'orge a barbes lisses. Bul. App. Bot. and Plant Breed., 12:105-127. 1921.
22. WEXELSEN, H. Quantitative inheritance and linkage in barley. Hereditas, 18:307-348. 1934.

LIMESTONE MOBILIZES PHOSPHATES INTO KOREAN LESPEDEZA[1]

WM. A. ALBRECHT and A. W. KLEMME[2]

KOREAN lespedeza has found wide acceptance as a forage crop to replace clovers and similar crops which have been recognized as sensitive to the soil's low supply of calcium. Since this newer legume is a nitrogen fixer, we may be inclined to ascribe to it the protein content commonly accepted for clover hays. This is apt to be done irrespective of the soil conditions under which the crop is grown. Since the lime level of the soil is a significant factor in determining nitrogen fixation by soybeans, for example, the question arises whether Korean lespedeza, on those soils too deficient in lime for success with clover, can produce as high a protein concentration in the forage as when given limestone or phosphates. In an attempt to supply the answer to this question, attention was given to the composition of the lespedeza harvest on the experimental plats of the Department of Field Crops of the Missouri Agricultural Experiment Station, given these soil treatments.

Samples of the lespedeza hay were gathered on August 7, 1938, from 12 plats as quadruplicates of the three treatments, namely, (a) no treatment, (b) superphosphate, and (c) limestone and superphosphate. The samples were separated into the grass and lespedeza portions and relative percentages of each determined. Weights of the hay crop were taken and the samples of lespedeza as separated analyzed for their contents in nitrogen, calcium and phosphorus with the results given in Table 1. The roots were also harvested in specified areas and similarly handled. No analyses were made of the grass. In the calculations, the grass portion was assigned the nitrogen content of 1.2%, and taken to have the same phosphorus and calcium contents as those in the lespedeza fraction of the hay.

Perhaps the first significant item in the data is the much larger yield increase of hay by the combined treatments of limestone and superphosphate than by the superphosphate alone. In the former treatment this effect amounted to an increase of 82.9%, and in the latter only 16.6%. No limestone additions were made as a single treatment which would serve to separate the effects.

Such a response in the form of increased crop weight is decidedly significant in pointing out that even though lespedeza may do fairly well on Putnam silt loam without soil treatment, it does better to the extent of over 80% when this soil is given the treatments of limestone and phosphorus, both recognized as essential on this soil type if it is to grow sweet clover or other legume crops successfully.

More significant than the increased crop weight, however, are the changes in crop composition, especially in nitrogen, as a consequence of soil treatment with limestone. When only superphosphate was supplied, the nitrogen composition was increased insignificantly, or

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from 1.79 to 1.81%. When limestone supplemented the phosphate, the nitrogen content rose to 2.09%, or an increase in absolute of 0.30%, or comparatively, of more than 17%. When the increased yields and the higher concentrations of nitrogen are converted into protein harvest per acre, the superphosphate used alone increased this 31.5%, while the limestone and superphosphate together gave an increase of 146.3%. Some of the differences are more clearly shown in Fig. 1.

TABLE 1.—*Influence of limestone on mobilizing phosphates into Korean lespedeza and on forming protein in the plants*

Soil treatment	Yield per acre, lbs	Calcium			Phosphorus				Nitrogen		Protein, lbs per acre
		%	Lbs per ton	Lbs per acre	%	Lbs per ton	Lbs per acre	Increase lbs per acre	%	Lbs per ton	
					Hay						
No treatment	762 (60%)*	0.935	18.7	7.12	0.189	3.78	1.44	—	1.79	35.8	85.2 (73.9)
Phosphate	800 (90%)	0.986	19.7	8.76	0.201	4.02	1.78	0.34	1.81	36.2	100.5 (97.2)
Limestone & phosphate	1394 (100%)	0.945	18.9	13.17	0.189	3.78	2.53	1.09	2.09	41.8	182
					Stubble and Roots						
No treatment	454	0.557	11.1	2.52	0.243	4.86	1.03	—	1.99	39.8	56.4
Phosphate	463	0.635	12.7	2.94	0.240	4.80	1.11	0.08	2.19	43.8	63.5
Limestone & phosphate	579	0.661	13.2	3.84	0.212	4.24	1.22	0.19	1.98	39.6	71.7

*Figures in parenthesis represent the percentage of lespedeza in the hay and the protein harvest per acre corrected for the grass admixture. Chemical analyses were made under the direction of Dr. L. D. Haigh, Department of Agricultural Chemistry.

In terms of the concentrations of phosphorus and calcium in the crop, each remained the same in the hay whether from the plats with no treatment or from those given limestone and superphosphate together. In the hay where superphosphate was used alone, both calcium and phosphorus moved into it to greater concentrations than in the other treatments. Since the yields were not increased extensively by this single treatment, this increased concentration may represent the influence of some limiting factor in holding down the yield through which the increased phosphate concentration may have resulted.

The increased total phosphorus in the larger crop where limestone was used as a supplement to phosphate indicates the beneficial effect by liming in mobilizing the phosphorus into the crop. The use of superphosphate only gave an increase in the total crop phosphorus of slightly more than 1/3 pound, or about 25%; but, when limestone was also introduced, this same phosphate application resulted in giving an increased phosphorus harvest in the crop of 1.09 pounds, or an increase of 75%. The corresponding increases in the total calcium taken by the crop amounted to 23% and 85%, respectively.

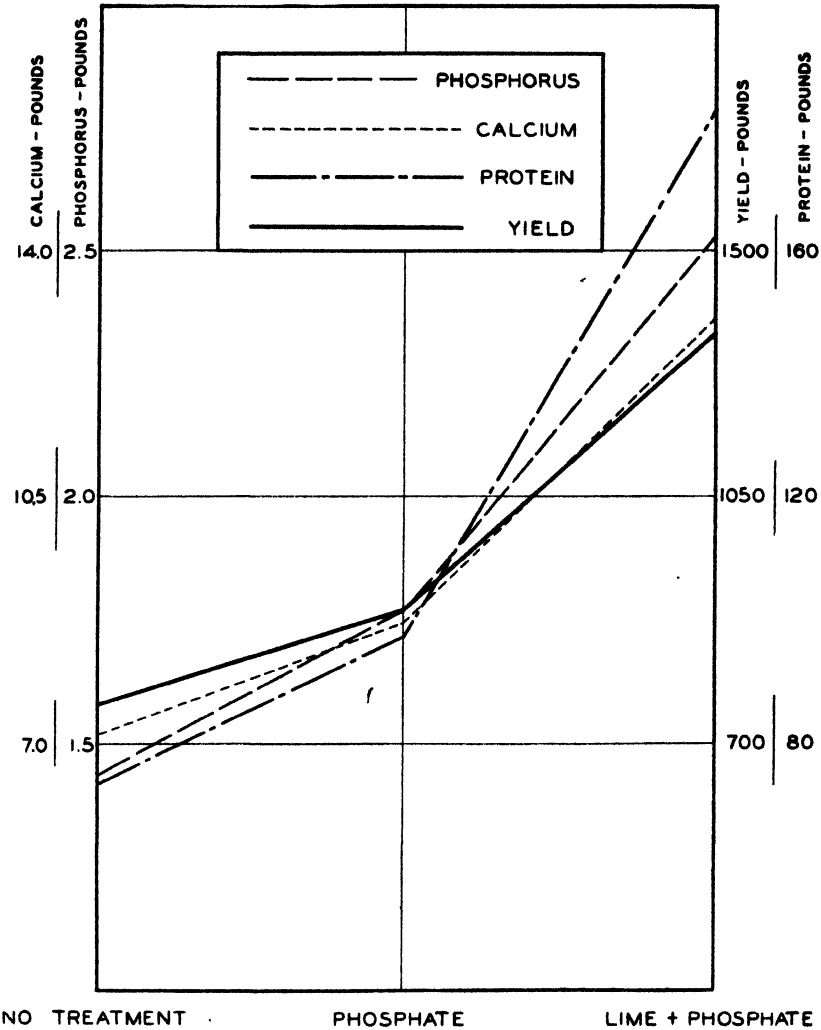

Fig. 1—Nutrient harvest in the lespedeza crop as influenced by superphosphate and by lime and superphosphate combined as soil treatments.

Such increases in forage yields of lespedeza for this one trial in the better season of 1938, and particularly such an increased content in nitrogen, suggest that the efficiency of this legume as a nitrogen fixer may be improved on some soils by the soil treatments of limestone and phosphate. It suggests that on the less fertile soils, such as Putnam silt loam, Korean lespedeza cannot reach its highest efficiency as a soil improver, nor as a feed, without attention to soil treatments. When these consist of limestone and phosphates, they not only give increased crop and nitrogen harvest, but their use together may serve to mobilize the phosphorus into the crop more effectively for an increase in the total crop harvest and in its relative content of protein.

THE NUMBER OF REPLICATED SMALL PLAT TESTS REQUIRED IN REGIONAL VARIETY TRIALS[1]

J. B. HARRINGTON[2]

THE present trend in the comparative testing of new varieties or treatments is toward having a large number of tests well distributed. The many combinations of climatic, soil, and topographical conditions which occur in any large agricultural area are represented very roughly at the best by the results obtained on the existing experiment stations. The station tests give results which apply precisely to only the very limited environments of the stations and therefore serve satisfactorily only the few farmers who reside close by. The remaining farmers, possibly 90% of the total number, have to be satisfied with more or less misleading approximations, unless, in addition to the station tests, supplementary local tests are conducted.

The situation is well illustrated in the Province of Saskatchewan. There are five experiment stations in the Province serving a block of farming country roughly 400 miles by 300 miles with a large diversity of soils and climates and a total of nearly 20,000,000 acres devoted annually to grain crops It is generally considered that the results obtained at the experiment stations, augmented occasionally by some cooperative tests with farmers, are inadequate, particularly when information on the comparative performance of new varieties is desired urgently by farmers in all parts of the Province.

It is felt that supplementary tests are valuable, but opinions vary considerably as to how many are needed. Considering the cost of the tests, it is desirable to conduct the minimum number that will provide the necessary information. Recently, several hundred well-distributed tests were run in Saskatchewan and the present paper makes use of the data in dealing with the question of how many tests are required.

PROCEDURE

In 1934, the Saskatchewan Wheat Pool, realizing the need for more tests, conceived the ambitious scheme of financing a program of variety testing on a large scale. After considerable effort and expense a series of 355 five-variety latin square tests of barley was conducted in 1935. These tests were so successful that the same organization promoted in 1936, in addition to 50 barley tests, a series of 321 tests of wheat varieties, and in 1937 and 1938 a further 684 tests of wheat varieties. Altogether these series totalled 1,410 tests containing 27,573 plats and 110,292 separately labelled rows.

The summarized data on each successful test of 1935, 1936, and 1937 were published by the Saskatchewan Wheat Pool (3, 4, 5).[3]

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[2]Professor of Field Husbandry.

[3]Figures in parenthesis refer to "Literature Cited", p. 299. In the publications recognition is given of the assistance of the Dominion Experimental Farms System, the University of Saskatchewan, and particularly the individual farm cooperators.

Throughout the project each test consisted of a compact block of plats each plat comprising four rows 10 feet long and 1 foot apart and protected from end effects by spring sown winter wheat. Each test was sown on summer-fallow under field conditions away from buildings and surrounded by a grain crop. Notes were taken on height, straw strength, neck strength, and date of maturity by the cooperators, only the two center rows of each plat being used. The same rows were later harvested, wrapped, tied, and labelled by plats and sent to experiment stations for the determination of yield, weight per measured bushel, thousand kernel weight, and protein content. The yields were taken in grams per plat (1/2178 acre) and are expressed in the tables in bushels per acre. The cooperators (especially selected farm boys and girls from 15 to 18 years old), while assisted in many cases, worked essentially independently by following detailed mimeographed and printed instructions on how to lay out and carry through a test.

Throughout the tests the latin square method was used. Each year a balanced arrangement identical for all tests of that year was employed. The value of balanced arrangements was emphasized by Gosset (2) in 1936. This arrangement allowed, with no sacrifice of validity, an appreciable saving of expense in the routine procedures of packeting seed, writing labels, threshing the grain, compiling the data, and in the preparation of instructions and report forms. In the barley tests of 1935 a five replicate latin square was used. The 1936 wheat test consisted of a four replicate latin square. In 1937 it was desirable to test six varieties of wheat. With very little sacrifice of precision and a large saving in money the test was arranged in the form of a three replicate modified latin square[4] instead of a four replicate figure. The use of the modified latin square arrangement was referred to by Snedecor (6) in 1934. Fisher's (1) variance method was used to analyze the data on grain yield, the character which will be considered in this paper. The formula $1/N\sqrt{a^2+b^2+c^2,\ldots n^2}$ was used in determining the mean standard error for a series of tests.[5] The standard error of a difference was calculated by the formula $\sqrt{a^2+b^2}$ and this was multiplied by 1.77 to furnish a figure which, if exceeded, would indicate that one variety excelled another by odds of at least 19 to 1.

In the present study the problem was resolved into a search for answers to three questions: How many tests must be made to reveal accurately the comparative merits of the varieties with respect to (a) the Province as a whole, (b) a given cereal variety zone, and (c) a particular condition in or portion of a given cereal variety zone? *The last question is the crucial one* since it concerns directly the large majority of individual farmers.

[4]A latin square with columns more than one plat wide. In this case the three columns were each two plats wide.

[5]This formula takes account of the variability within varieties at each location and its use here is somewhat comparable to using the "remainder" for the estimate of error in a variance analysis including all of the data from the various tests. The necessary differences obtained as a result of using this formula may therefore vary somewhat from the results obtained from the more correct method of comparing the varieties by pairs throughout the sets of tests by "Students" or some other pairing method. However, the work entailed in using a pairing method throughout the study would be enormous and the results would be very cumbersome to present. The "variety x test" interaction, which some biometrical writers have recommended as the correct source of the estimate of error for mean variety differences in tests at several locations has proved quite unsatisfactory for that purpose and therefore is not used here. The writer considers that the method employed is the most feasible one under the circumstances and believes that the errors it introduces are of no practical importance in the present study.

While there is much diversity of soil and climate in Saskatchewan, the Province may be divided fairly definitely into four main soil-climatic zones, *viz.*, (a) the semi-arid open plains, (b) the transitional open plains region, (c) the parked dark soil area, and (d) the forest lands. For purposes of grain variety recommendations, the soil-climatic zones have been divided into cereal variety zones designated by the soil-climatic zone number plus a letter.

RESULTS OF 1935 BARLEY TESTS

Of the 355 barley tests sown in 1935, a total of 261 were considered to be reliable for biometrical analysis. There was a large range of variation among the tests. The standard error of the mean yield of a variety in percentage of the mean yield of the test (SEv%) was distributed as follows: 82 were 2 to 4%, 103 were 5 to 7%, 44 were 8 to 10%, 6 were 14 to 16%, 5 were 16 to 19% and 3 were 20 to 22%. The SEv% was below 5% in 31 4% of the tests. The average SEv% for all tests was 6 9%. These errors, while higher than most of those at experiment stations, somewhat comparable station tests at Saskatoon in 1935 averaging 5 3%, compared fairly favorably with them. The range in yield within tests had the following distribution.

Range in bushels:	1 8	9 16	17 24	25 32	33 40	41 48	49-56	57-64
No. of tests:	21	62	109	44	15	5	4	1

The mean range in yield per test was 20.7 bushels per acre. The distribution of yield differences necessary to provide odds of 19 to 1 that one variety excelled another was

Yield difference in bushels	2 4	5 7	8 10	11 13	14 16	17-19
No. of tests:	46	123	61	19	8	4

The mean necessary difference was 7.05 bushels per acre.

PROVINCE-WIDE BASIS

Considering the Province as a whole, How many tests seem desirable? Different numbers of tests were taken at random from the entire 261 tests and the averages compared. Altogether 12 random sets of 5 tests, 6 of 10 tests, 5 of 20 tests, 2 of 40, and 2 of 80 were studied. The results appear in Table 1. The sets of 5 tests varied considerably from each other and from the average for the 261 tests (set 28), but 10 of the 12 sets had the same yielding order of varieties as set 28 and the significant varietal differences of set 28 were matched in 24 out of 36 comparisons in the 5 test sets. The agreement of each set with set 28 is noted in the last column of the table. In several cases a difference in one set was significantly different from the corresponding difference in another set.

The 10-test sets showed less variation and better agreement with set 28 than the 5-test sets. In each of five of the six sets one variety comparison lacked significance, whereas in set 28 all comparisons were highly significant. The sets of 20 tests agreed well with set 28 except for one comparison in set 20. The 40- and 80-test sets all agreed reasonably well with set 28.

To summarize, all sets of 40 tests or more may be said to have represented the whole Province satisfactorily.

TABLE 1.—*Summarized yields in bushels per acre and in percentage of Regal of four barley varieties in 261 five-replicate plat tests distributed over Saskatchewan in 1935, with comparison of results from different assortments of random sets of tests.*

Set	No. of tests	Summarized yields for each set							Neces-sary diff., bu.*	Agree-ment with set 28†
		Regal, bu.	Trebi		OAC 21		Colsess			
			Bu.	%	Bu.	%	Bu.	%		
1	5	34.2	42.8	125	27.6	81	30.6	89	2.57	P
2	5	60.1	69.4	115	51.6	86	50.6	84	3.08	P
3	5	31.0	41.4	134	28.6	92	31.2	101	2.06	P
4	5	33.2	39.2	118	29.2	88	33.2	100	2.43	P
5	5	40.2	48.2	120	35.8	89	39.4	98	1.92	F
6	5	38.4	46.8	122	35.2	92	39.0	102	2.08	P
7	5	40.6	49.2	121	35.6	88	38.2	94	2.03	F
8	5	40.0	42.4	106	33.0	83	33.2	83	2.84	P
9	5	29.2	38.8	133	26.2	90	27.8	95	2.35	F
10	5	41.2	51.6	125	37.0	90	33.8	82	3.97	VP
11	5	51.6	69.6	135	45.4	88	47.4	92	3.31	F
12	5	27.6	33.6	122	24.2	88	24.4	88	2.29	P
13	10	39.3	47.5	121	35.5	90	39.2	100	2.00	P
14	10	40.3	45.8	114	34.3	85	35.7	89	1.59	G
15	10	40.3	54.2	134	36.0	89	37.6	93	1.41	F
16	10	34.5	42.6	123	30.6	89	29.1	84	1.75	P
17	10	47.2	56.1	119	39.6	84	40.6	86	2.30	G
18	10	32.1	40.3	126	28.9	90	32.2	100	2.00	F
19	20	39.8	46.7	117	34.9	88	37.5	94	1.35	F
20	20	37.4	48.4	129	33.3	89	33.4	89	1.83	F
21	20	43.8	55.2	126	37.8	86	39.1	89	1.22	G
22	20	40.4	48.2	119	35.6	88	38.6	96	1.59	F
23	20	39.9	48.2	121	34.3	86	36.4	91	1.54	G
24	40	38.6	47.5	123	34.1	88	35.4	92	0.95	VG
25	40	40.1	48.2	120	34.9	87	37.5	94	0.92	VG
26	80	39.4	47.9	122	34.5	88	36.5	93	0.66	VG
27	80	36.4	47.0	129	32.6	90	33.9	93	0.66‡	VG
28	261	37.8	46.4	126	33.0	92	34.6	95	0.50‡	—

*Necessary difference is the difference required for odds of at least 19:1 that one variety yielded more than another. If the reader prefers to use odds of 40 to 1 in this or in any of the other tables the necessary differences as given should be increased by 13%.
†Agreement with set 28: P = poor; F = fair; G = good; VP = very poor; VG = very good.
‡Estimated.

ZONE BASIS

Some of the larger cereal zones contain annually more than 3,000,000 acres of grain crops and it is important that accurate information on varietal performance in each zone and even in different parts of the same zone be obtained. Here again the question arises, How many tests are necessary?

Two random lots of 10% of the total number of tests in a zone and the combination of these two sets, or 20% of the total number, were taken for each zone. The results are given in Table 2. These results may be summarized as follows: There was significant disagreement between random lots and zone averages in 15 cases out of 24 concerning the 10% randoms and in 6 cases out of 12 concerning the com-

bination or 20% randoms Although more reliable than the smaller randoms, the 20% randoms were misleading in half the cases which

TABLE 2 —*Average yields in bushels per acre of four barley varieties in 261 five replicate plat tests distributed over Saskatchewan in 1935 with results from random groups of sets compared with the average results from each zone*

Variety	Random sets of tests				Random sets of tests				Random sets of tests			
	1st	2nd	Both	All tests	1st	2nd	Both	All tests	1st	2nd	Both	All tests
	Zone 1A				Zone 1B				Zone 2A			
No tests	2	2	4	22	2	2	4	21	4	4	8	38
Regal	47	40	43	31	41	21	31	29	35	37	36	30
Trebi	60	62	61	41	46	31	38	38	50	48	49	45
OAC 21	45	41	43	29	24	17	20	26	37	42	39	30
Hannchen*	43	34	38	31	—			—				—
Colsess	49	40	45	31	33	24	28	27	38	39	38	32
Nec diff bu	4 4	6 5	3 9	1 4	4 8	5 0	3 5	1 2	2 3	3 0	1 9	0 9
Agreement†	P	VP	VP		P	P	P		G	P	F	
	Zone 2B				Zone 2C				Zone 3A			
No tests	6	6	12	63	1	1	2	7	2	2	4	18
Regal	38	38	38	37	22	26	24	30	26	23	24	25
Trebi	49	48	48	45	58	31	45	43	44	43	43	38
OAC 21	29	36	33	31	30	16	23	27	32	34	33	28
Colsess	37	37	37	36	31	27	29	34	31	23	27	26
Nec diff	3 0	2 3	1 9	0 9	5 9	4 0	3 5	2 1	3 2	2 7	2 5	1 2
Agreement†	P	G	VG		P	F	G		G	P	P	
	Zone 3B				Zone 3C				Zone 3D			
No tests	1	1	2	3	2	2	4	25	1	1	2	6
Regal	36	34	33	42	31	59	45	50	57	53	55	45
Trebi	46	44	45	48	35	68	51	59	65	51	58	49
OAC 21	35	35	35	42	28	50	39	44	54	34	44	35
Colsess	27	26	27	31	27	44	35	41	43	37	40	37
Nec diff	6 1	11 7	6 5	6 7	3 1	6 1	3 4	1 3	4 5	6 5	3 9	2 3
Agreement†	P	G	F		G	G	VG		P	P	P	
	Zone 3E				Zone 4A				Zone 4B			
No tests	3	3	6	27	2	2	4	21	1	1	2	10
Regal	38	37	38	31	69	42	55	52	42	38	40	38
Trebi	41	44	43	37	67	55	61	63	61	46	54	44
OAC 21	30	31	31	26	64	40	52	48	42	46	44	37
Colsess	32	34	33	29	44	44	44	44	30	47	39	37
Nec diff	2 1	2 7	1 7	1 1	5 7	4 3	3 6	1 6	6 7	5 9	4 4	1 9
Agreement†	G	G	VG		VP	P	F		VP	VP	P	

*Hannchen alternating with Peatland as the fifth variety happened to be in all tests in Zone 1A
†Agreement with average of all tests P = poor F = fair G = good VP = very poor, VG = very good

clearly indicates the need of more tests than 20% of the number carried; that is, more than 52 tests for the whole Province.

BASIS OF LOCAL CONDITIONS

Perhaps one of the most valuable results of having a large number of tests is the fact that some of the tests reveal certain important varietal differences which may be obscured or missing in a small number of tests. The data were therefore studied to see whether the large number of tests were justified on the basis of contributing information not otherwise obtained, or, if obtained, not significant or not clearly observable This study included the data from five zones.

In zone 1A, five random lots of 4, 8, and 12 tests were taken. Only the 12-test random gave an accurate picture of the zone results. Some parts of the zone suffered drought while other parts had good rainfall. The five lowest yielding tests were taken in comparison with the five highest yielding ones. Since the low yields were undoubtedly due to drought conditions (the tests were sown reasonably early on summer-fallow), these tests indicate the relative drought resistance of the varieties. The two sets differed significantly, the results indicating that Hannchen, Colsess and, to a certain extent, Trebi, were more resistant to the drought than OAC 21 and Regal whereas the latter two prospered relatively more under favorable conditions. Even the 12-set random did not include enough tests of these two sets to reveal the comparison clearly. The results are shown in Table 3.

TABLE 3 —*Average yield for different sets of tests in bushels per acre and in percentage of Regal for results from Zone 1A*

Variety	5 low tests		5 high tests		Random 4 tests		Random 8 tests		Random 12 tests	All 22 tests	
	Bu	%	Bu	%	Set 1 %	Set 2 %	Set 1 %	Set 2 %	%	Bu	%
Regal	15	100	58	100	100	100	100	100	100	31	100
Trebi	22	146	64	110	142	137	139	127	133	41	132
OAC 21	11	76	54	94	100	94	97	96	97	29	94
Hannchen	19	126	52	90	88	123	103	112	103	31	100
Colsess	17	118	47	81	105	100	102	99	101	31	100
Nec. diff	1 9		4.2							1.4	
Agreement with all*					P	P	G	P	G		

*P = poor, G = good

Similar studies were made of the results for zones 3A and 3C without striking results. For these zones possibly a quarter as many tests as were run would have been sufficient to represent the zones clearly.

A study of zone 2A results was made on the basis of different soil types. The results are given in Table 4. The supremacy of Trebi was significantly greater on the Regina clay, a lacustrine soil, than on the Weyburn loam, a glacial soil. Regal was very significantly outyielded by OAC 21 and Colsess on the Regina clay, but the three varieties yielded about alike on the Weyburn loam. These differences

were not obtained in either the four-test randoms nor in the combination eight-test randoms In fact, the random eight happened to include only 1 of the 10 tests of the two special groups discussed

TABLE 4 – *Average yields for different sets of tests in Zone 2A in bushels per acre and in percentage of Regal*

Variety	Random sets						Five typical tests on				All 38 tests	
	4 tests		4 tests		8 tests		Regina clay		Weyburn loam			
	Bu	%	Bu	%	Bu	%	Bu	%	Bu	%	Bu	%
Regal	35	100	37	100	36	100	22	100	23	100	30	100
Trebi	50	143	48	130	49	136	57	264	35	151	45	150
OAC 21	35	101*	31	85	33	93	27	127	24	93	30	100
Colsess	38	109	37	99	37	104	34	157	23	99	32	107
Nec diff	2 3		3 0		1 9		2 5		1 7		0 9	

*OAC 21 yielded 0 3 bu more than Regal

Zone 2B, being large, furnished material for several assortments of sets from among the total of 63 tests This zone is 265 miles from northwest to southeast and 110 miles wide at the widest part One 12-test random and four special groups of tests were studied The summarized data are given in Table 5

TABLE 5 --*Average yield for different sets of tests in Zone 2B in bushels per acre and in percentage of Regal*

Nature of tests	Regal		Trebi		OAC 21		Colsess		Nec diff, bu
	Bu	%	Bu	%	Bu	%	Bu	%	
All 63	37	100	45	122	31	84	36	97	0 9
Random 12	38	100	48	126	33	89	37	97	1 9
Five light soil	36	100	41	115	23	65	36	102	2 7
Five western	31	100	37	116	23	73	28	88	3 0
Five southeast	53	100	59	111	50	94	49	91	3 8
Five lowest yield	12	100	21	172	11	90	19	152	1 3

In the group of five lowest yielding tests, Trebi and Colsess yielded 72% and 52%, respectively, above Regal compared with 22% and 0% above, respectively, in the 63-test averages for the zone These low yield tests reveal the superior drought resistance of Trebi and Colsess as compared with Regal and OAC 21 No indication of this superiority was obtained from a random set of 12 tests The group of five tests taken from a central light soil area showed OAC 21, unlike the other three varieties, to be very significantly lower in yield than in the zone average. The five southeast tests show an OAC 21 vs. Colsess difference which was significantly different than the OAC 21 vs. Colsess difference in the zone averages It is apparent that having a large number of tests in zone 2B furnished information which might easily have escaped notice or else been of no significance if the number of tests had been materially less.

Summarizing, the work on the 1935 results shows that (a) as few as 20% of the tests represented the Province satisfactorily, that (b) about 20 to 50% of the tests were required to represent a cereal zone accurately, and that (c) all or nearly all of the 261 tests were needed to reveal the relationships of the varieties under particular conditions or in certain definite parts of the cereal zones.

RESULTS OF THE 1936 WHEAT TESTS

Of the 321 wheat tests of 1936, 194 were successful. These tests were for the purpose of comparing the new stem rust resistant variety Thatcher with well-known standard varieties in all parts of the Province. The results for the three varieties which were in all tests (the fourth variety was one of Garnet, Ceres and Reliance according to the location of the test) are given by zones in Table 6. The varieties did not have constant yield relationships in the different zones. For example, Marquis was relatively at its best in zones 1, 3C, and 3D where Reward was relatively at its poorest. Again, Thatcher yielded much more in relation to Marquis in zones 2A and 3B than in zone 1, indicating that Thatcher was less able than Marquis to do well under drought conditions.

TABLE 6.—*Summarized yields in bushels per acre and in percentage of Marquis of three wheat varieties in 192 four-replicate plat tests distributed throughout Saskatchewan in 1936.*

Zone	No. of tests	Marquis		Thatcher		Reward		Nec. diff., bu.
		Bu.	%	Bu.	%	Bu.	%	
1	46	10.2	100	11.3	111	8.9	87	0.31
2A	17	15.4	100	18.6	121	14.9	97	0.61
2B	41	16.2	100	18.9	117	15.5	96	0.52
2C	2	2.5	—	4.0	—	4.5	—	0.72
2	60	15.5	100	18.3	118	14.9	96	—
3A	14	19.2	100	22.7	118	19.4	101	0.94
3B	8	23.0	100	28.9	126	22.3	97	1.14
3C	23	25.0	100	28.4	114	20.8	83	0.95
3D	10	24.6	100	27.8	113	20.8	85	0.87
3E	27	16.8	100	19.9	118	15.7	93	0.73
3	82	21.7	100	25.5	118	19.8	91	—
4A	3	19.0	100	22.0	116	17.3	91	1.83
4B	3	12.7	100	14.7	116	13.0	102	2.50
4	6	15.9	100	18.4	116	15.2	96	—
Province	194	16.7	100	19.4	116	15.3	92	0.23

A detailed study of results from different numbers of tests taken at random from two of the large zones was made. The results on zone 1 are given in Table 7. In zone 1 it was found that three 10-test randoms agreed only fairly well with the 45-test average, whereas a 20-test random agreed very well. The ability of Reward to do as well as Marquis under some severe drought conditions was revealed by the 10 highest and 10 lowest yielding tests. When as few as 23 of the 45 tests were taken, this relationship was not clear cut as only 3 of the low-yielding tests were included.

TABLE 7.—*Summarized yields in bushels per acre of four wheat varieties in 45 four-replicate plat tests in Zone 1 in 1936, with comparison of results from different assortments of random tests.*

Set	No. of tests	Description of tests	Marquis, bu.	Reliance, bu.	Thatcher, bu.	Reward, bu.	Nec. diff., bu.	Agreement with set 1
1	45	All zone	10.2	11.2	11.2	8.8	0.31	——
2	2	Random	11.0	13.0	15.0	11.0	1.20	Poor
3	2	Random	5.5	7.5	8.0	8.5	1.34	Poor
4	2	Random	18.5	18.0	17.5	15.5	1.57	Poor
5	5	Random	14.4	15.0	14.6	12.0	0.78	Good
6	5	Random	10.8	12.4	12.8	10.4	0.99	Fair
7	5	Random	7.0	9.2	8.8	7.0	1.00	Fair
8	5	Random	6.6	7.2	7.2	6.2	0.56	Fair
9	10	Random	12.6	13.7	13.8	11.2	0.63	Good
10	10	Random	6.8	8.2	8.0	6.6	0.57	Fair
11	10	Random	9.8	10.0	10.1	8.7	0.81	Fair
12	20	Random	9.7	11.0	10.9	8.9	0.42	Good
13	10	High yield	18.3	19.3	19.5	14.7	0.78	Good
14	10	Low yield	4.3	4.7	5.0	4.5	0.50	Poor

The data for zone 2B were sampled on the basis of sub-zones as this zone contains some widely different examples of the transitional soil-climatic area between the open plains and the park lands. The results are presented in Table 8. The total of 41 tests was represented poorly to fairly well by three of the random sets of 10 tests. A random set of 20 tests agreed well with the zone averages. The 41 tests of the zone were then divided into four sections on a geographic basis. Marquis and Thatcher were significantly closer together in yield in the north and west portions than in the southeast or the southwest divisions, again indicating that Marquis could do better relatively

TABLE 8.—*Summarized yields in bushels per acre of five wheat varieties in 41 four-replicate plat tests in Zone 2B in 1936. Comparison of results from different assortments of random tests and in different zone subdivisions.*

Set	No. of tests	Description of tests	Marquis, bu.	Ceres, bu.	Thatcher, bu.	Reward, bu.	Reliance, bu.	Nec diff., bu.	Agreement with set 1
1	41	All zone	15.9	—	18.8	15.5	—	0.52	——
2	5	Random	17.8	—	19.8	14.8	—	1.19	Poor
3	5	Random	16.4	—	18.4	16.8	—	1.10	Poor
4	10	Random	17.1	—	19.1	15.8	—	1.35	Fair
5	10	Random	18.4	—	22.9	20.3	—	0.84	Poor
6	10	Random	15.8	—	17.3	13.5	—	0.76	Fair
7	20	Random	17.1	—	20.1	16.9	—	0.79	Good
5	13	Southwest	17.0	—	21.1	17.4	18.9	0.84	——
6	2	Random	20.5	—	22.5	20.5	23.5	3.96	Poor
7	4	Random	15.8	—	18.0	13.0	16.3	1.10	Poor
8	10	Southeast	23.5	26.8	28.4	23.2	—	1.30	——
9	2	Random	18.0	17.5	20.0	16.5	—	1.23	Poor
10	4	Random	23.5	25.8	28.5	26.8	—	1.59	Poor
11	12	North	13.0	13.9	13.9	12.0	—	0.94	——
12	6	West	6.5	7.5	7.5	5.7	—	0.96	——

than Thatcher under dry conditions. Small randoms (of 15 and 30%, respectively) from the southwest and southeast sections agreed poorly with the section totals.

Summarizing, the work on the 1936 results shows that (a) nearly half of the tests were needed to represent a zone satisfactorily and that (b) all or nearly all of the tests were needed in order to obtain accurate comparative variety reactions to specific conditions or in local areas.

RESULTS OF 1937 WHEAT TESTS

The 1937 wheat tests were of particular interest because they carried all three of the new highly stem rust resistant varieties Apex, Renown, and Thatcher, the first two not having been placed previously in widespread farm-cooperator tests. The drought in the open plains region was the most severe on record and of the 334 tests sown only 136 were successful. Table 9 shows by zones the summarized results on five of the varieties

TABLE 9. - *Summarized yields in bushels per acre and in percentage of Marquis of five wheat varieties in 136 three-replicate plat tests distributed throughout Saskatchewan in 1937.*

Zone	No. of tests	Marquis, bu.	Reward		Thatcher		Apex		Renown		Nec. diff. bu.
			Bu.	%	Bu.	%	Bu.	%	Bu.	%	
1	9	5.8	4.5	78	5.8	100	5.7	98	4.5	78	0.52
2A	8	6.5	5.6	86	6.9	106	6.8	105	5.5	85	0.50
2B	25	6.0	4.6	77	6.9	115	6.1	102	5.3	88	0.46
2C	0	—	—	—	—	—	—	—	—	—	—
2	33	6.1	4.8	79	6.9	113	6.2	102	5.3	87	—
3A	16	11.2	10.3	92	13.5	121	11.2	100	11.0	98	0.74
3B	9	20.5	17.1	83	22.8	111	20.6	100	19.6	96	1.02
3C	25	16.5	13.6	82	18.9	115	16.6	101	15.7	95	0.89
3D	12	21.7	21.8	100	25.1	116	23.3	107	20.9	96	1.21
3E	24	11.0	9.3	85	12.6	115	11.7	106	11.2	102	0.73
3	86	15.1	13.3	88	17.5	116	15.6	103	14.7	97	—
4A	7	29.0	26.0	90	33.0	114	31.9	110	29.0	100	2.24
4B	3	16.3	14.0	—	17.0	—	15.3	—	14.3	—	3.16
4	10	25.2	22.4	89	28.2	112	26.9	107	24.6	98	—
All	138	13.2	11.4	86	15.1	114	13.6	103	12.6	95	0.30

The tests proved to be excellent for revealing the relative behavior of the varieties under a range of conditions varying from extreme drought to favorable situations. In zone 1, Reward and Renown did poorly compared with Marquis. Thatcher, usually well above Marquis, was equal to it in this zone and Apex maintained equality with Marquis. Apex alone had sufficient drought resistance to approach its normal yield relative to Marquis. The nine successful tests in zone 1 were the result of sowing 105 tests. If only a portion of these tests had been sown it is probable that the number of successful ones would have been too small to furnish comparisons of any significance.

Renown did definitely better in the park and forest area (zones 3 and 4) than on the open plains (zones 1 and 2). Thatcher appeared to

excel Renown in adaptation, doing well not only in zones 3 and 4 but also in much of zone 2. Thatcher, however, proved distinctly less able than Marquis to do well under severe drought conditions, although showing greater adaptability than Reward, as in 1936 Apex proved the most adaptable of the three by yielding well in all zones. The adaptation comparison is brought out by the variation in yield of each variety in percentage of Marquis, *viz.*, Renown, 24%; Thatcher, 21%; and Apex, 12%.

Summarizing the 1937 results, it appears evident that the number of tests in the open plains zones was not unnecessarily large. In most of the other zones it appeared desirable to have all or nearly all of the tests that succeeded. In two zones there were too few tests to be of real value.

PROPORTION OF SUCCESSFUL TESTS

Table 10 shows a statistical summary of all of the tests according to cereal variety and soil-climatic zones. In the Province as a whole the highest proportion of successful tests was in the favorable season of 1935, the next highest in the dry season of 1936, and a decidedly lower percentage in the very dry season of 1937. Zone 4, the moist forest area, showed its highest proportion of successful tests, 91% in 1937, when the drought was so severe in the open plains region that the proportion of successes in zone 1 was only 9% and in zone 2 only 32%. As the three years were drier than the long time average, the average proportion of successful tests, 58.7%, is a very conservative estimate of the proportion of tests likely to be satisfactory in future testing programs of this kind. The results indicate that, in the appor-

TABLE 10. *Statistical summary of the number of individual cooperative tests and percentage of successful test in each year in both the cereal variety and the soil climatic zones.*

Zone	1935			1936			1937			% satisfactory tests, 3 yrs.
	No of tests	Satisfactory tests		No of tests	Satisfactory tests		No of tests	Satisfactory tests		
		No.	%		No.	%		No.	%	
1	86	43	50	98	46	47	105	9	9	33.9
2A	51	38	75	40	17	55	36	8	22	53.5
2B	76	63	83	55	41	65	61	25	41	64.6
2C	8	7	88	7	2	29	7	0	0	40.9
2	135	108	80	102	60	59	104	33	32	58.9
3A	22	18	82	19	14	74	20	16	80	78.7
3B	4	3	75	10	8	80	12	9	75	76.9
3C	33	25	76	32	23	72	33	25	76	74.5
3D	7	6	86	12	10	83	15	12	80	82.4
3E	32	27	84	40	27	68	34	24	71	73.6
3	98	79	81	113	82	73	114	86	75	76.0
4A	23	21	91	4	3	75	7	7	100	91.2
4B	13	10	77	4	3	75	4	3	75	76.2
4	36	31	86	8	6	75	11	10	91	85.5
Province	355	261	74	321	194	60	334	138	41	58.7

tionment of tests, three times as many should be sown in areas like zone 1 as are required in a completed form, whereas in areas like zone 4 for every six sown five may be expected to succeed.

DISCUSSION

Having a large number of replicated tests distributed over an agricultural region has certain definite advantages compared with using a small number of tests. One of these advantages is the greater reliability of the information obtained. Another advantage is the reduction in the estimate of error giving significance to smaller differences. A third advantage is that many tests reveal clearly the distinctive behavior of the varieties under certain seasonal conditions as well as in particular soil-climatic environments. The only important disadvantage is the greater expense of a large number of tests.

Since the principal purpose of tests of different varieties or treatments which are available to the farmer is to furnish information which will be valuable in advising him, it is obvious that an insufficient number of tests or a poor distribution of them is not satisfactory. When tests are placed systematically throughout an area the problem of distribution is taken care of. But the problem of number of tests is not solved until sufficient tests are run to provide an accurate answer to the agronomic aspect of a given farmer's question, "What variety (fertilizer, method, etc.) shall I use?" no matter in what local area that farmer lives. The results of the present study indicate that, in a large agricultural region served by five experiment stations, a total of more than a thousand variety tests sown during a 3-year period did not result in an unnecessarily large number of successful tests.

It appears that in order to have a certain number of successful tests in a given area, consideration should be given to the soil and climatic conditions of that area as well as to any unusual limiting factors. It is almost inevitable that a proportion of the tests will be destroyed by crop pests, drought, and other factors not under perfect control.

The number of tests required depends upon the objects of the tests. *From this study it would seem that in order to ascertain quickly the comparative performance of new varieties of an important crop in the different parts of a large agricultural area, literally hundreds of tests should be run for at least two representative years.*

SUMMARY

1. A study was made of data from several hundred replicated small plat tests of barley and wheat to determine the number of tests required for accurate comparative results in a given area. The tests studied were distributed throughout the farming area of Saskatchewan and totalled 27,573 plats, each plat consisting of four 10-foot rows.

2. For the Province as a whole random lots of 40 tests gave close approaches to the results obtained with 261 tests (1935 results).

3. For separate soil-climatic and cereal variety zones a quarter to a half as many tests as run in 1935 and 1936 gave results similar to

those from the larger numbers, except that differences were less frequently significant. The drought in 1937 reduced the number of satisfactory tests to 138 and in only three zones could the number that year be considered larger than necessary.

4. For sampling of local areas within zones results obtained from distinctly fewer tests than those run did not reveal or bring out differences that otherwise were found. Similarly, the differential reactions of the varieties to particular conditions were not shown clearly where small numbers of tests were used.

5. It was concluded that the number of cooperative tests run in Saskatchewan in 1935 to 1937 was not excessive and that materially reducing the number of such tests would have been detrimental to the purpose for which they were planned.

LITERATURE CITED

1. FISHER, R. A. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 5. 1934.
2. GOSSET, W. S. Cooperation in large scale experiments. Supplement to Jour. Roy. Stat. Soc., 3:115 122. 1936.
3. SASKATCHEWAN COOP. WHEAT PRODUCERS, LTD. Barley varieties in Saskatchewan, 1935. Regina, Sask. 1937.
4. ———. Junior cooperative wheat variety tests, 1936. Regina, Sask. 1937.
5. ———. Wheat varieties in Saskatchewan, junior cooperative tests, 1937. Regina, Sask. 1938.
6. SNEDECOR, G. W. Calculation and Interpretation of Analysis of Variance and Co-variance. Ames, Iowa: Collegiate Press. 1934.

SOIL-CONSERVING AND SOIL-IMPROVING CROP ROTATIONS FOR THE PALOUSE[1]

SAM L. SLOAN, ARDEN W. JACKLIN, AND VERLE G. KAISER[2]

THIS paper deals with the problem of the introduction and establishment of soil-conserving and soil-improving crop rotations in the Palouse of eastern Washington and adjacent Idaho. The infonnation presented has been developed from the demonstration project of the Soil Conservation Service located on the South Fork of the Palouse River in the vicinity of Moscow, Idaho, and Pullman, Washington.

The Palouse is a relatively new country having been plowed out of prairie only a little more than five decades ago. Large scale operations are employed on the crop land which constitutes approximately 75% of the total acreage (7, 8).[3] A typical farm unit has been about 500 acres divided into two major fields. Farm cropping systems have been largely soil depleting, conducive to erosion and accelerated run-off. Soil loss through erosion and decline in fertility have simultaneously progressed under past systems of management to the extent that productivity has decreased and approximately one-fifth of the cultivated land is submarginal for cash crops. Soil-conserving and soil-improving rotations in combination with crop residue utilization and improved methods of tillage have been found to be the most important means of checking these conditions Terracing and strip-crossing had not been applied to the area because of topography, farming methods, and limited diversity of crops. Soil conservation is being accomplished by treatment of the soil itself to enable it to absorb and store the moisture it receives.

DESCRIPTION OF THE AREA

McGrew and Horner (2) state that, "The typical Palouse topography consists of a series of somewhat dune-shaped loessial hills, which, in general, have south and southwest slopes that are longer than and not so steep as the north and northeast slopes. A considerable part of the cultivated land has slopes ranging from 10 to 40 %. Some of the land has more than 50 % slopes. A characteristic feature of this topography is the steep amphitheatre-like north and northeast slopes. Narrow valleys of alluvial land make up a well-defined drainage system."

The area lies at an approximate elevation of 2,700 feet.

The normal precipitation at Pullman, Wash., based on records over a period of 43 years, is 20.75 inches. However, only about 79% of this is effective moisture as 21% is lost immediately as run-off (2).[4] The annual rainfall has varied from

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[3]Figures in parenthesis refer to "Literature Cited", p. 313.

[4]Four-year average (1932–35) from 2.3 acre watershed cropped to a wheat-fallow system.

14.12 inches in 1935 to 30.87 inches in 1927. Approximately 76% of the precipitation falls from September 1 to March 31. Snowfall occurs intermittently from December 1 to March 1, but total accumulation seldom exceeds 20 to 24 inches. The peculiar dune-like topography and prevailing winds from the southwest are conducive to severe snowdrifting. The snow is blown from the south slopes and hilltops and is piled up on the upper part of the leeward slopes (3). A considerable amount of soil is carried with the snow. These drifts on the north slopes cause an uneven distribution of winter moisture.

Erosion over the Palouse area is caused principally by run-off from rains and melting snow. Most of it occurs during the winter and spring seasons. January, February, and March are the critical erosion months. Combinations of frozen ground, snow, rain, and chinook winds contribute to severe erosion. The average annual soil losses from wheat-fallow land are approximately 9 tons per acre (2).

The soils are predominately of the Palouse series. The following types are of major importance: Palouse silt loam, Palouse silt loam shallow phase, and Palouse silty clay loam shallow phase (2).

Palouse silt loam, the most extensive type, is characterized by a dull dark brown silt loam A_1 horizon of 10 to 12 inches. This is underlain by a brown to yellowish brown silt loam or silty clay loam A_2 horizon to a depth of about 30 inches. The B horizon is a yellowish brown silty clay or silty clay loam and may extend to a depth of 60 inches. This is underlain by a C horizon, a silty-clay loam which is of variable depth and extends to the underlying basalt. The entire profile is quite friable. When dry, the upper horizons show a weakly columnar structure and the subsoil shows a definite columnar structure (2).

The Palouse silt loam shallow phase occurs exclusively on hilltops and ridges where soil-building forces were such that a shallow solum was developed.

The Palouse silty clay loam shallow phase has developed as a result of erosion and downhill movement of soil by tillage operations. True topsoil is lacking, or is so thoroughly mixed with the subsoil that it is entirely indistinguishable.

Before the advent of farming in the area, the Palouse was a rolling prairie country supporting a dense cover of bunchgrasses and legumes. The climax cover was composed chiefly of blue bunch wheat grass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), big bluegrass (*Poa ampla*), and Sandberg's bluegrass (*Poa secunda*). Other associated species were junegrass (*Koelaria cristata*), *Astragalus* spp., *Lupinus* spp., yarrow (*Achillia milifolium*), and balsam root (*Balsamorhiza sagittata*).

CROPS ADAPTED TO THE PALOUSE

Wheat is the most important crop grown in the Palouse. Winter wheat has been grown more extensively than spring wheat although both produce satisfactory yields. Soft white wheats predominate largely because of their yielding capacity. Yields vary considerably, depending upon seasonal climatic conditions and crop sequence, and range between 20 to 50 bushels per acre on average fields (6). The Palouse has never known a crop failure.

Field peas are grown extensively for seed, commercial peas, and livestock feed. The early smooth-seeded variety Alaska is grown almost to the exclusion of other types. The average pea yield is 12 to 14 bushels per acre (6).

Oats and barley are of minor importance in the area. They are usually grown for feed, although a small amount of malting barley is produced. Oats generally produce approximately 60 bushels per acre and barley approximately 30 bushels

(6). Variations, however, are great and yields up to 100 bushels of oats and 60 bushels of barley per acre are not uncommon.

Intertilled crops, including corn, sorghum, cotton, and soybeans, have not been adapted to the area. Climatic conditions and topography definitely limit their use.

In 1938 a considerable acreage of flax and commercial mustard were produced in the area. Previous to this year, mustard was practically unknown and flax has been produced only to a very limited extent.

The entire area is adapted to the production of sweet clover and alfalfa. They have geen grown on a very small proportion of the land and until recently were seldom brought into specific rotations being sown chiefly on conveniently located or favored areas (5).

Alfalfa is used principally for hay and usually produces only one cutting with a yield of 1½ to 3 tons per acre, depending upon site location. Occasionally, alfalfa is left for seed but production is very uncertain. Seed yields vary from a failure to 150 pounds per acre. Hardy variegated alfalfas are produced almost exclusively.

Sweet clover has multiple uses but is most commonly used as green manure or as pasture. To a limited extent it is used for hay and seed production. Tall biennial white sweet clover predominates. As a green manure crop, it produces approximately 10 to 12 tons of green matter per acre. When used for pasture it provides from three to five animal months grazing per acre. As a hay crop it outyields alfalfa about 1 ton per acre. Seed production is more certain than for alfalfa in most years and yields are approximately double.

Grasses have been of minor importance in the area. With the introduction of soil-conserving practices, however, they have assumed major importance. Certain perennial grasses are invaluable for their erosion-resisting properties either in pure stands or in mixtures with legumes. Outstanding grasses today are smooth bromegrass (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), slender wheatgrass (*Agropyron pauciflorum*), tall meadow oatgrass (*Arrhenatherum elatius*), and orchard grass (*Dactylis glomerata*). Other grasses, including ecological strains of native species, are being developed to fill specific needs.

The Palouse is favorably adapted to grass seed production and should rapidly develop into an important source of high quality seed.

PAST CROPPING PRACTICES AND RESULTANT EFFECTS ON SOILS AND EROSION

Comparatively little land was cropped prior to the year 1875. After the Civil War, land was taken up rapidly and during the period from 1880 to 1890 most of the area was plowed and used for wheat production.

Soon after the breaking of the native sod (some 55 years ago) the predominant cropping system was that of continuous grain cropping. Wheat was most commonly produced, but some barley and oats were occasionally grown. The high fertility of the virgin soil was in time reduced by this constant cropping to a point where it was no longer profitable to raise successive grain crops. Accordingly, summer fallow was introduced one year out of three or four in a cycle (4). Within 20 years, by 1900, it became necessary to fallow on alternate years in order to make available a sufficient amount of nitrogen for a profitable grain crop. Fallowing also controlled the annual weeds.

Field peas were introduced about 1918 and by 1930 approximately one-half of the land ordinarily fallowed was diverted to the production of this crop.

In the grain-fallow and grain-pea systems, the soils have been seriously mistreated. Crop residues were generally burned soon after harvest and no crops were grown for soil improvement and fertility maintenance. Under this treatment "the soils have lost at least 35% of their organic matter, 25% of their nitrogen and much of their capacity for absorbing moisture" (6) These soil losses have caused the original open, friable, and mellow condition of the soil to be replaced by a compacted condition. The surface soil under this condition puddles easily and seals over during precipitation periods. The combination of reduced soil organic matter content, less pervious soil, and lack of protective winter cover has resulted in accelerated soil and water losses Detailed conservation surveys show that most hilltops, ridges, and upper south slopes have lost from 75% to all of their original topsoil The acreage involved amounts to about 15% of the area. The major part of the area has lost over 25% of its original topsoil In addition to direct topsoil loss, the washing of gullies through fertile flats and slopes has resulted from the inability of upper slopes to absorb the precipitation they received

COVER AS RELATED TO EROSION

The degree of resistance against erosion provided by different crops and land treatments within a rotation may arbitrarily be divided into three classes, *viz.*, complete erosion control, semi-erosion control, and no erosion control. In the Palouse area, complete erosion control is that cover condition obtained by close-growing perennial vegetation. This type of cover affords as complete protection against erosion as is economically possible to obtain Semi-erosion control is that condition obtained by properly utilized grain stubble, standing grain stubble, or a fairly close-growing cover of biennial legumes in pure stands or in mixture with grasses. Properly utilized stubble involves rough tillage and leaving the trash on or mixed with the surface soil. Slight erosion and some water loss may occur on land with this cover condition during the spring run-off period, but protection is afforded against severe soil and water losses. No erosion control is that condition occurring when the land has no protective cover and also has a finely worked surface soil condition. Summer fallow planted to winter wheat and clean-tilled crops are typical examples. This condition permits severe soil and water losses during the critical erosion periods.

The amount of soil and moisture lost from different cover conditions has been quantitatively measured by the Pacific Northwest Soil Conservation Experiment Station at Pullman, Wash. (2). Complete erosion control is represented by an established cover of perennial grass[5] which lost an average of 0.56 ton of soil per acre annually and 2.07% of the total percipitation. Semi-erosion control condition is represented by standing wheat stubble[6] which lost an average of

[5]Only a fair stand.

[6]An average of four stubble conditions.

69 tons of soil per acre annually and 5.76% of the precipitation. No erosion control is represented by summer fallow seeded to winter wheat in the fall which lost an average of 16.79 tons of soil per acre and 12.30% of the precipitation.

DEVELOPMENT OF CROP ROTATIONS

The introduction of soil- and water-conserving farming methods into the Palouse required two major changes in farm management. First, it was necessary to introduce soil-building and soil-conserving crops in systematic rotations with a corresponding decrease in summer fallow; and, second, to introduce the use of distinct types of treatments for different soil types, slopes, and erosion conditions occurring in a single large field.

Two classes of rotations were developed to meet the situation, *viz.*, soil-improving rotations and soil-conserving rotations

Soil-improving rotations are designed for use on fields with gentle slope and slight to moderate erosion (1). Erosion control is effected by the use of green manure crops, crop residue utilization, and improved tillage methods to improve the physical condition of the soil and maintain soil productivity. The three commonly used long-time rotations in this class are (a) sweet clover two years, grain two years, fallow one year, and grain one year; (b) sweet clover and peas one year, sweet clover one year, grain two years, peas one year, and grain one year; and (c) sweet clover two years and grain two years.

As a class, these soil-improving rotations are generally used on Palouse silt loam soils.

Soil-conserving rotations are designed for use on fields with relatively steep slopes and areas of moderate to severe erosion This class provides a maximum amount of vegetative cover for erosion control in addition to improving the physical condition of the soil and maintaining soil productivity.

The four most common types of rotations in this class are (a) alfalfa and grass four years and grain two years; (b) grass or alfalfa and grass three years and grain three years; (c) sweet clover two years, grass three years, and grain two years; and (d) grass three years, grain two years, sweet clover two years, and grain two years.

As a class soil-conserving rotations are adapted to Palouse silt loam shallow phase and Palouse silty clay loam shallow phase soils although they are oftentimes used on Palouse silt loam soils where slope is excessive or erosion is severe.

EVALUATION OF ROTATIONS FOR SOIL AND WATER CONSERVATION

To evaluate recommended soil-conserving and soil-improving crop rotations, comparison is made with past soil-depleting cropping practices. In this comparison, major emphasis is placed on erosion-controlling values, and secondary emphasis on crop returns.

In the grain-fallow and grain-pea soil-depleting systems, the soil is subject to severe erosion during critical months for at least one year in every two-year cycle. No erosion control is secured during the winter

months after summer fallow or after peas. In both cases, the soil is finely pulverized and puddles easily, which prevents rapid moisture absorption. A combination of these conditions results in heavy run-off accompanied by serious soil loss. Winter wheat planted on fallow or pea land, seldom makes sufficient fall growth to offer resistance

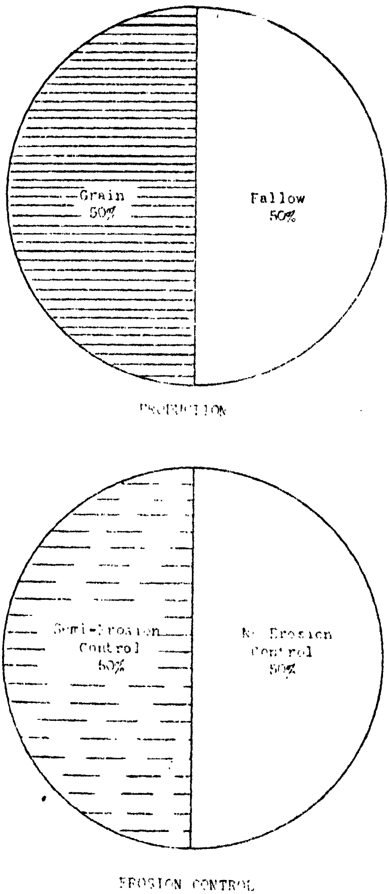

Fig. 1.—Soil-depleting cropping systems. Grain-fallow rotation.

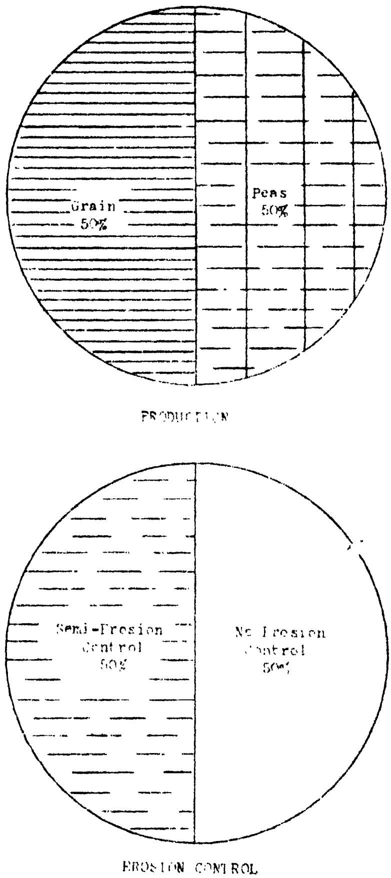

Fig. 2.—Soil-depleting cropping systems. Grain-peas rotation.

against erosion. Semi-erosion control is afforded during the erosion period following grain crops, providing the grain stubble is left standing or is properly utilized. The amount of erosion control afforded by these rotations is graphically illustrated in Figs. 1 and 2. A distinct weakness of both the grain-fallow and grain-pea systems, aside from accelerating erosion, is the fact that they provide income to the farmer from only one source.

In the soil-improving rotations, tall white blossom biennial sweet clover (*Melilotus alba*) is generally used as the soil-improving crop. It may be seeded alone, in a mixture with a perennial grass or with peas as a companion crop, depending upon the soil conditions in the individual field and the amount of erosion control necessary. Sweet clover has multiple uses, but it has its greatest utilization as a dual-purpose crop for pasture and soil improvement. It is also used for hay or seed.

Rotation A is six years in length and includes sweet clover two years, grain two years, fallow one year, and grain one year. The sweet clover is most commonly seeded alone or with grass, as this rotation is used on areas which are not suited to the production of peas. The first-year sweet clover or sweet clover and grass produces a semi-erosion controlling cover. During favorable years, sweet clover and grass may produce cover sufficient to control erosion completely, but such stands are generally fall pastured which reduces their erosion-controlling value. The second year sweet clover is almost always plowed in the fall when the soil is dry. The resulting rough and open soil condition provides a high degree of erosion control. The first crop following is commonly spring sown. Second year sweet clover is consequently classed as semi-erosion controlling.

The effects of the sweet clover soil-improving crop make it possible to produce two successive grain crops following the green manure crop and at the same time produce normal or above normal yields. This combination of sweet clover and annual cropping eliminates two years of summer fallow. The heavy and uniform stubble produced on the fields following sweet clover provides a true semi-erosion controlling condition when properly utilized in the fall or left standing over winter. The year of fallow provides no erosion control. However, the effects of stubble utilization in the previous years, together with the improvement in the physical condition of the soil obtained by the sweet clover crop makes this year markedly less critical than the fallow year in the grain-fallow system. The final grain crop produced in the rotation cycle is similar in erosion control to the two crops produced following sweet clover. This rotation therefore provides five years of semi-erosion control and one year of no erosion control during each six-year cycle. This is graphically illustrated in Fig. 3.

The farm income from this rotation is more nearly balanced than in the case of the previously described soil-depleting systems, owing to the fact that income is secured from both grain production and forage utilization for livestock production.

Rotation B in the soil-improving group is also six years in length and is very similar to rotation A just described. It differs only in that peas are included in the rotation. This rotation is adapted only to better classes of farm land having low erosion potentials. In it, the sweet clover is usually sown with peas as a companion crop and peas also replace summer fallow the fifth year.

Sweet clover seeded with peas is classed as furnishing no erosion control in the fall of the first year, owing to the fact that the stand is inferior to the stand secured when the sweet clover is seeded alone or with grass. Root development of the clover is light and the harvest-

ing operation on the peas cuts the topgrowth almost level with the surface of the soil. Grass is not included with sweet clover and peas because competition of the peas and sweet clover limits its establishment and growth. Although spreading the pea straw at the time of harvesting provides a slight amount of control, soil loss during the

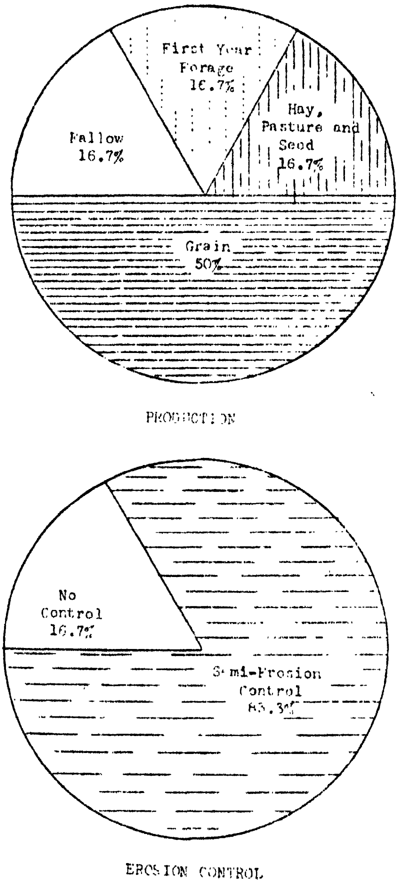

Fig. 3.—Soil-improving rotations. Sweet clover 2 years; grain 2 years; fallow 1 year; and grain 1 year.

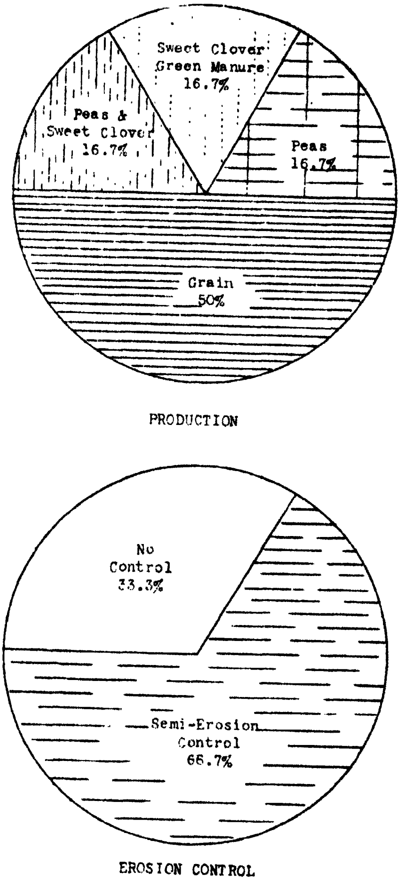

Fig. 4.—Soil-improving rotations. Sweet clover and peas 1 year; sweet clover 1 year; grain 2 years, peas 1 year; and grain 1 year.

following winter months may be severe. The second-year sweet clover in this rotation is generally plowed for green manure at the early blossom stage. The land following the plowing down of sweet clover is in a rough and open condition. If no subsequent tillage is practiced before the winter erosion period, semi-erosion control is provided for that season. The sweet clover is very seldom utilized for hay or pasture because farmers who raise peas extensively usually operate large

units and have few livestock. The two successive grain crops following the sweet clover are comparable to the two grain crops of similar placement in rotation A and provide semi-erosion control. Peas the fifth year of the rotation provide no erosion control as very little cover remains after harvesting on soil that is in a finely pulverized condition due to intensive cultivation in the preparation of the seedbed. The final grain crop provides semi-erosion control. Rotation B, therefore, provides four years of semi-erosion control or two years of no erosion control in every six-year period. This is illustrated in Fig. 4.

Farm income from this rotation is more nearly balanced than in the case of the two-year soil-depleting systems, but in actual practice is less balanced than the six-year sweet clover and grain-fallow system. This is due to the fact that the second-year sweet clover in this rotation is not generally utilized by livestock and, therefore, farm income is chiefly derived from grain and peas.

Rotation C, the third soil-improving rotation, is four years in length and consists of two years of sweet clover and two years of grain. It has been developed for use on the more severely eroded crop land where it is impractical to retire large areas from cereal crop production for long periods of time. Rotation C is also very commonly used on farms where livestock production is of major importance. The sweet clover in this rotation is usually seeded with a perennial grass. Utilization of first-year forage for pasture in the fall is an accepted practice. Second-year sweet clover and grass in this rotation is generally pastured very heavily through the late spring and early summer, and the aftermath is turned under for soil improvement. Fall utilization, however, prohibits classing this as complete erosion control. Second-year sweet clover and grass is usually plowed rough and handled in the same manner as described under rotation A. Both first-year and second-year sweet clover and grass, therefore, are classed as semi-erosion controlling as are the two successive grain crops which follow. Total resistance against erosion is very high consisting of four years of semi-erosion control in each four-year cycle. A graphic illustration is given in Fig. 5. Farm income from this rotation is balanced by livestock production and cereal grain production.

Soil-conserving rotations involve seeding mixtures of alfalfa and perennial grasses or pure seedings of perennial grasses. Alfalfa and grass are almost always used for hay. Pasturing is confined almost exclusively to aftermath. The close-growing cover produced by grass mixtures with alfalfa provides practically complete erosion control. The effect of plowing under alfalfa in preventing erosion persists much longer in the soil than does the effect of plowing under sweet clover. Grass in pure stands in these rotations is ordinarily used for seed production. Mixtures of alfalfa and grass are used in these rotations and are set up so that different seeding rates, different species, and different mixture proportions are closely correlated with soil and erosion conditions.

Rotation A in the soil-conserving class is six years in length and consists of four years of alfalfa and grass and two years of grain. This is the most important rotation in class III because in addition to providing a high degree of erosion control it fits in ideally with the

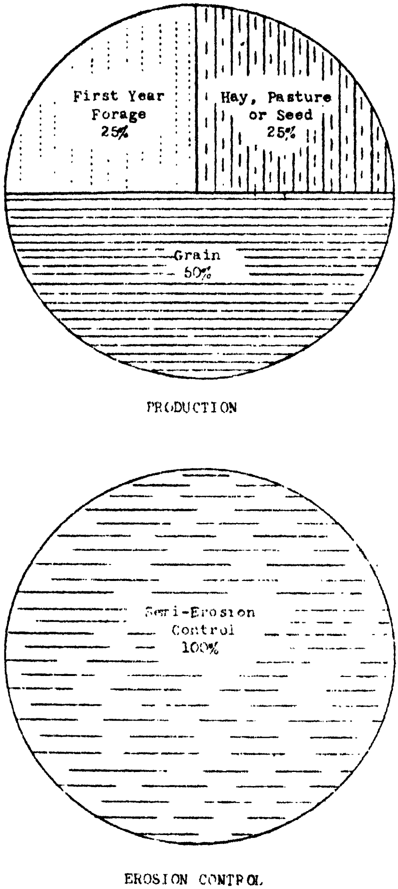

Fig. 5.—Soil-improving rotations. Sweet clover 2 years and grain 2 years.

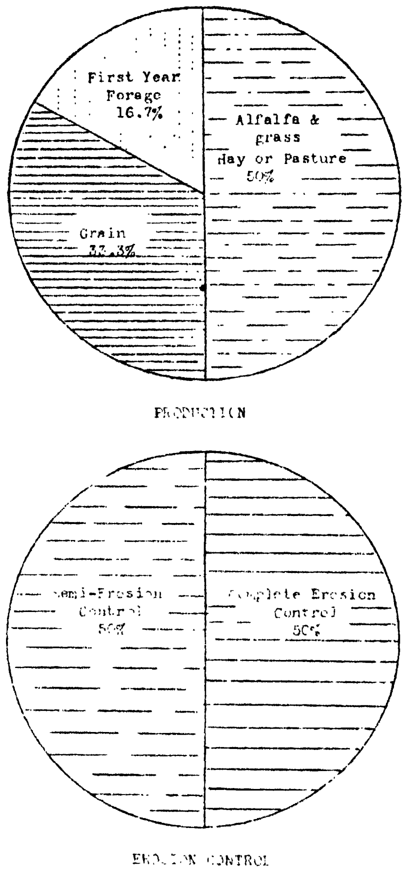

Fig. 6.—Soil-conserving rotations. Alfalfa and grass 4 years; grain 2 years.

six-year sweet clover and grain rotations of class II (a) and (b) previously described. Reference is made to Table 1 showing this relationship.

TABLE 1.—*Relationship between class 2, rotation A and class 3, rotation A, when both are used in a single large field.*

1st yr.	2nd yr.	3rd yr.	4th yr.	5th yr.	6th yr.	7th yr.	8th yr.
			Area I				
Fallow	Grain	Sweet clover	Sweet clover	Grain	Grain	Fallow	Grain
			Area II				
Alfalfa and grass	Alfalfa and grass	Alfalfa and grass	Alfalfa and grass	Grain	Grain	Alfalfa and grass	Alfalfa and grass

The three years during which a cover of alfalfa and grass are on the field provide complete erosion control. In the fourth year the alfalfa and grass are fall plowed and the soil is left in a rough, open condition during the winter. This provides semi-erosion control. Two successive grain crops are then produced and afford semi-erosion control when the stubble is properly utilized. Erosion control effected by this rotation consists of three years of complete control and three years of semi-erosion control during each six-year period. This is a very great increase over the soil-depleting and erosion-inducing grain-pea or grain-fallow systems, and is also over twice as effective as the soil-improving rotations. A graphic illustration of the amount of erosion control afforded by this rotation is shown in Fig. 6. Income from this six-year alfalfa and grass rotation is very well balanced. The income is derived from cereal grain production, livestock production, and from the sale of hay.

Rotation B in the soil-conserving class is also six years in length and differs from rotation A in that the alfalfa and grass appear only three years in every six. A modification of this rotation includes grass for seed production for three years instead of alfalfa and grass. This rotation is used on areas of slightly less slope and erosion than rotation A. The three successive grain crops following the alfalfa and grass are handled in much the same way as the successive crops following sweet clover.

The third grain crop yields enough to make this system profitable and fallow is thereby entirely eliminated. Erosion control in rotation B consists of two years of complete control, afforded by the first two years of the alfalfa and grass, and of four years of semi-erosion control afforded by one year of rough, fall-plowed alfalfa and grass and by three years of properly utilized grain stubble. Rotation B affords slightly less erosion control than rotation A in the soil-conserving class, but is much superior to any rotation in the soil-improving class. The amount of control is graphically illustrated in Fig. 7.

Rotation C in the soil-conserving class, consisting of two years of sweet clover, three years of grass, and two years of grain, is designed primarily for grass seed production on steep and eroded areas. The two years of sweet clover afford semi-erosion control. The first two years of grass afford complete erosion control, while the year the grass is plowed and the two succeeding years of grain are classed as semi-erosion controlling. This gives two years of complete control and five years of semi-erosion control in each seven-year cycle. The amount of control is graphically illustrated in Fig. 8. This rotation is gaining in importance because of the emphasis being placed on grass seed production in the Palouse. The improvement given the soil by the sweet clover is reflected in very heavy grass seed crops.

Rotation D in this soil-conserving class is nine years in length and consists of three years of grass, two years of grain, two years of sweet clover, and two years of grain. It differs only from rotation B in that a soil-building crop of sweet clover is seeded in the rotation. It differs from rotation C in that the immediate effects of the sweet clover are used for grain production rather than for grass seed production. It has been devised principally to increase or maintain soil fertility and

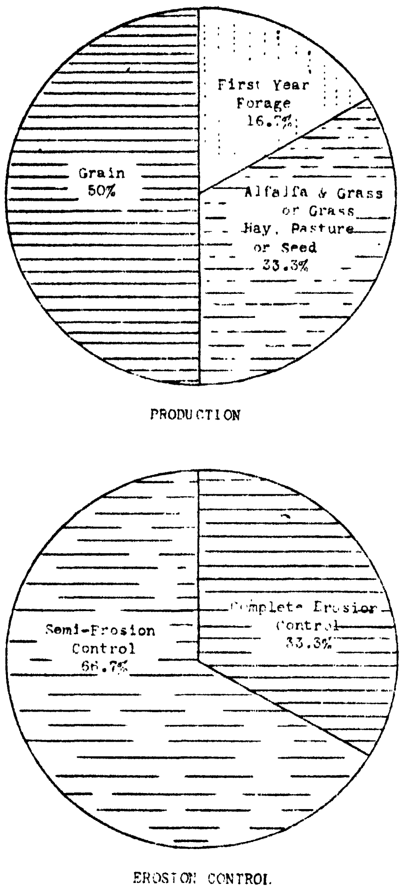

Fig. 7—Soil-conserving rotations. Grass or alfalfa and grass 3 years and grain 3 years.

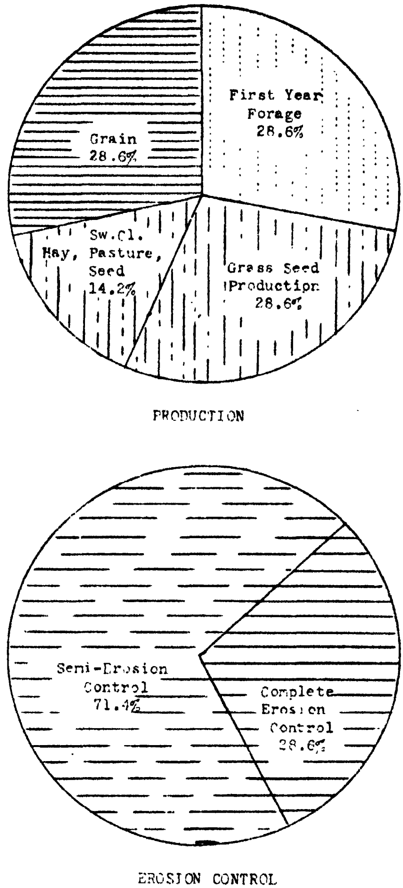

Fig. 8.—Soil-conserving rotations. Sweet clover 2 years, grass 3 years; and grain 2 years.

productivity. Erosion control obtained by the use of this rotation consists of two years of complete control and seven years of semi-erosion control in every nine-year cycle. The two years of complete control are made up of the first two years during which a grass cover is on the land. The seven years of semi-erosion control consist of one year of fall-plowed grass, two years of sweet clover, and four years of properly utilized grain stubble. The amount of control is graphically illustrated in Fig. 9. This rotation provides for a well-balanced farm income. It includes the production of grain, pasture, hay, and forage seeds.

SUMMARY

Crop land makes up approximately 75% of all lands in the South Palouse project. The use of soil-improving and soil-conserving crop

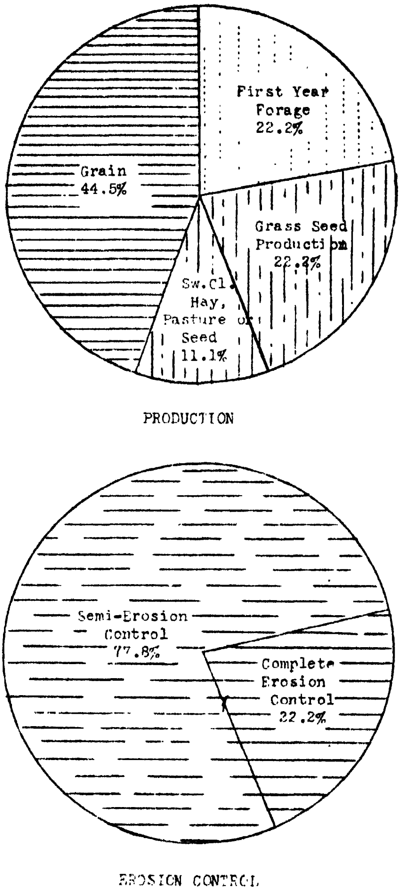

Fig. 9.—Soil-conserving rotations. Grass 3 years; grain 2 years; sweet clover 2 years, and grain 2 years.

rotations, combined with proper utilization of crop residues, are the most important measures of conserving soil and water.

The grain-fallow and the grain-pea soil-depleting cropping systems were in general use on most of the area until five years ago. In these systems the fields were unprotected from erosion during half of the critical erosion periods and had only semi-protection during the other half of the erosion periods in each two-year cycle.

Soil-improving rotations have been planned for crop lands having gently sloping and only moderately eroded soils. These rotations are designed to improve the physical condition of the soil and to increase or maintain the fertility and productiveness. They are as follows:

1. The six-year rotation (A) including two years of sweet clover, two years of grain, one year of fallow, and one year of grain produces a semi-erosion controlling cover on the land during five years out of every six. The sixth year in the cycle has no erosion control. This rotation is adapted to areas having moderate erosion potentials and not adapted to pea production.
2. The six-year rotation (B) including one year of sweet clover and peas and one year of grain has a semi-erosion controlling cover on the land four years out of every six, with the fifth and sixth years having no cover. This rotation is used only on the less eroded and gentler slopes on the farm.
3. The four-year rotation (C) including two years of sweet clover and grass and two years of grain produces a semi-erosion controlling cover on the land every year in the cycle. For this reason, it is used on more severely eroded and steeper crop land areas than either rotations A or B.

Soil-conserving rotations, have been planned for use on the most severely eroded crop lands and on the steeper slopes. In these rotations the land has an erosion-controlling cover on it a major portion of the

years in every cycle. For this reason, these rotations not only improve the productivity and physical condition of the soil, but also provide protective vegetative cover. They are as follows:

1. The six-year rotation (A) including alfalfa and grass four years and grain two years ties in very closely with the six-year rotation including sweet clover as a soil-improving crop. In this rotation the fields have complete erosion control three years out of every six. The other three years they have semi-erosion control.
2. The six-year rotation (B) including alfalfa and grass three years and grain three years is slightly less stringent in erosion control than rotation A. Complete erosion control exists on the land two years in every six, the other years being in a semi-erosion controlling condition. The six-year rotation including grass three years and grain three years has the same erosion controlling properties. The grass in this rotation is most commonly utilized for seed production. This type of rotation is used only on the more fertile areas where the physical condition of the soil is in need of improvement, rather than improvement of fertility.
3. The seven-year rotation (C), including sweet clover two years, grass three years, and grain two years, places more emphasis on income from grass seed than from grain. Erosion is completely controlled three out of every seven years. The remainder of the time is a semi-erosion controlling condition.
4. The nine-year rotation (D), including grass three years, grain two years, sweet clover two years, and grain two years, is designed to improve the soil fertility and productivity in addition to the other advantages of rotation B. In this rotation the land has complete erosion control on it two years in nine, the other seven years being in semi-erosion controlling condition.

Soil conserving and soil-improving crop rotations balance farm income by diversification of sources.

LITERATURE CITED

1. HAFENRICHTER, A. L., and ROCKIE, W. A. Ecological aspects of soil erosion in the Pacific Northwest as determined by the reconnaissance erosion survey. Northwest Science, 11:No. 4. 1937.
2. MCGREW, P. C., and HORNER, G. M. Soil and water conservation investigations. Pacific Northwest Soil Conservation Exp. Sta., Pullman, Wash. Progress Rpt., 1931 35.
3. ROCKIE, W. A. Snowdrifts and the Palouse topography. Geograph. Rev., 24: No. 3. 1934.
4. ————. Some important effects of the summer fallow system of farming on soil erosion in the Pacific Northwest. Northwest Science, 7:No. 1. 1933.
5. SCHAFER, E. G., WHEETING, L. C., and VANDECAVEYE, S. C. Crop rotations. Wash. Agr. Exp. Sta. Bul. 344:1–74. 1937.
6. SEVERENCE, GEORGE, HUNTER, BYRON, and EKE, PAUL. Farming systems for eastern Washington and northern Idaho. (Idaho Agricultural Experiment Station, Washington Agricultural Experiment Station, and Bureau of Agricultural Economics U. S. Dept. Agr. in cooperation.) Idaho Agr. Exp. Sta. Bul. 173:1–83, 1930; and Wash. Agr. Exp. Sta. Bul. 244:1–83. 1930.
7. VOGEL, HAROLD A., and JOHNSON, NEIL W. Types of farming in Idaho. Part I, Agricultural Resources and Factors Affecting Their Use. Idaho Agr. Exp. Sta. Bul. 207:1–60. 1934.
8. WILLARD, REX E., and JOHNSON, NEIL W. Present Land Uses—Washington, Types of Farming Series, Part 1. Wash. Agr. Exp. Sta. Bul. 288:1–40. 1933.

THE INFLUENCE OF SPACE AND ARRANGEMENT ON THE PRODUCTION OF SOYBEAN PLANTS[1]

R. G. WIGGANS[2]

THE soybean, like any other crop which is being produced in its border area of adaptation, presents many special problems, the answers to which must be sought in the area where the production of the crop is being attempted. This paper is the report of a study of the effect of space and arrangement of plants on the production of soybeans in the northeastern range of their production. This is only one of many problems which might be studied with interest and profit. Further information is needed on varieties, inoculation, fertilization, cultivation, the effect of length of day, and utilization.

Accepting the recommendations of the corn belt investigators as to the best method of distribution of the seed of soybeans for maximum production, cultivated rows 36 inches apart were used in the beginning as a standard method in the experimental work at the New York State College of Agriculture. By 1930 the width of row had been reduced to 28 inches, to the advantage of increased production. A solid drill varietal test was established in 1931 to include the more promising varieties for grain. Both cultivated rows, 28 inches apart, and solid drills, with rows 8 inches apart, have been used in varietal trials continuously since that date. Table 1 gives the results in bushels per acre for three of the several strains in these tests.

TABLE 1.—*Comparison between cultivated rows and solid drilling of soybeans.*

Year	Yield in bushels per acre								
	Cayuga			Seneca			65344		
	28 in rows	8 in. rows	Difference	28 in. rows	8 in. rows	Difference	28 in. rows	8 in. rows	Difference
1931	26.8	38.6	11.8	—	—	—	30.9	40.7	9.8
1932	25.0	37.4	12.4	28.0	38.2	10.2	24.0	36.1	12.1
1933	26.5	38.3	11.8	42.2	45.2	3.0	29.5	41.6	12.1
1934	30.4	31.9	1.5	39.9	42.0	2.1	32.8	37.5	4.7
1935	33.3	34.9	1.6	38.4	33.8	−4.6	30.9	32.4	1.5
1936	24.5	25.3	0.8	33.5	32.6	−0.9	26.4	28.4	2.0
1937	28.7	37.0	8.3	37.2	36.3	−0.9	30.6	36.1	5.5
Average			6.9			1.5			6.8

These results illustrate the advantage of the solid drill method over rows wider apart when early-maturing soybean varieties are used for the purpose of grain production. In only 3 out of 20 trials included in the table were the yields in the 28-inch cultivated rows as large as those in 8-inch solid drills. These three instances all occurred with

[1]Paper No. 225, Department of Plant Breeding, Cornell University, Ithaca, New York. Also presented at the annual meeting of the Society held in Washington, November 16, 1938. Received for publication December 27, 1938.

[2]Professor of Plant Breeding.

one strain, which happens to be the largest of the three, and during years when some lodging occurred in the solid plantings. The average difference between the two methods of planting for the three varieties was 18.5% for the period. Although not entirely comparable, a fact which prevents the formulation of definite conclusions, these data are highly indicative. The yields taken from separate varietal trials are not exactly comparable. The trials, however, were in close proximity, often directly adjoining on the same type of land which had received the same treatment.

The above results, together with those from other varieties tested during 1931-33, stimulated the present method study. The study involves the influence of space and arrangement on the production of Cayuga soybeans, a new and recently introduced variety in the New York area.

PLAN OF THE EXPERIMENT

The detailed plan used throughout the four years during which this experiment was continued is given in Table 2. The spacing within the rows varied from ½ inch to 6 inches, the distance between rows from 8 inches to 32 inches, while the number of plants per square foot varied from 1 to 18. One plant per square foot is approximately equivalent to a seeding rate of 1 peck per acre for Cayuga soybeans. During the first year, rows with widths of 20 inches, 28 inches, and 36 inches were included as well as a 9-inch spacing in the rows, but these were discontinued in later years as unnecessary for the purposes of the experiment. The question may arise as to why widths of 7, 14, 21, and 28 inches were not chosen instead of those which were used since such widths would lend themselves to the use of the ordinary grain drill. Experience has shown that an 8-inch row is about as narrow as can be conveniently employed where the work must be done by hand labor; further, the experimental equipment available was arranged for the widths as used; and, finally, it was thought that interpolation might be used with a fair degree of accuracy in estimating the yields for any desired width not included.

TABLE 2. *Plan of experiment to determine the spacing for optimum yields of Cayuga soybeans.*

Distance between plants in the row, inches	Number of plants per sq. ft. for different distances between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
½	—	—	18	12	9
1 or 1⅛*	18	12	9	6	4
1⅓ or 1½*	12	9	6	4	3
2 or 2¼*	9	6	4	3	2
3	6	4	3	2	1½
4 or 4½*	4	3	2	1½	1
6	3	2	1½	1	—

*These differences in spacing are made necessary in order to get the desired number of plants per unit area.

All plantings were made by hand in four-row blocks 20 feet long. Only the two central rows were harvested for this study since the wide variation in rate and spacing offered a maximum opportunity for competition, a factor of considerable importance in such an experiment. Each planting was repeated eight times. The

seed was specially graded, thoroughly mixed, and hand picked, and was of high germination. All seeds were counted, due consideration given to germination, and a 5% allowance made for field losses. Hand cultivation was practiced to eliminate weeds as a factor. Individual rows were handled as units during harvesting, threshing, weighing, and preliminary calculation of data, and finally, the two central rows were combined and considered as a unit. The experiment was always conducted on as uniform an area as possible which had been prepared as long ahead of planting as convenient and kept free of weeds by harrowing occasionally. The fertilizer was applied uniformly over the entire experimental plat with a grain and fertilizer drill, previous to the final preparation of the soil.

EXPERIMENTAL RESULTS

The yield of soybeans is affected materially by the spacing of the plants. Not only is the yield influenced by the distribution of the plants within the rows, but also by the distance between rows.

YIELDS FROM 1934-37

The data in Table 3 show the yields in bushels per acre for the four years during which this test was conducted. The construction of the table follows exactly the plan of the experiment as given in Table 2 Each individual yield in the table represents the average of eight repetitions, each replicate being the average of the two central rows of a four-row block.

The probable errors of the seasonal yields are extremely low for the first three years of the experiment and for the thicker plantings in 1937. The variation between repetitions in the thinner rates of planting in 1937 were much larger than in previous years, and were much the largest in the experiment. A difference between yields of 2.5 bushels per acre would be statistically significant in a very large percentage of the comparisons. The higher differential necessary in the thinner plantings in 1937 is due to the irregular stand resulting from unfavorable conditions immediately following the seeding operations. Heavy rains on a well-prepared clay soil resulted in a poor stand in some cases where the seeds were far apart. Under such conditions the individual seedlings were unable to break through, whereas thicker plantings resulted in good stands by virtue of the combined efforts of the many seedlings being able to break the crust. A set of adverse conditions such as existed in 1937 was thought necessary in this experiment in order to avoid erroneous conclusions, since such conditions occur more or less frequently and cannot be avoided.

A detailed study of this table shows extremely uniform relationships for the several years with the exceptions cited above. There are a few individual variations from year to year.

FOUR YEARS AVERAGE PRODUCTION

As summarized in the upper half of Table 4, the relationship between the various factors under study becomes clearer and all but one of the exceptions disappear. The ½-inch spacing in the 24-inch rows shows a smaller yield than the next thinner rate, a difference statistically insignificant.

TABLE 3.—*Effect of the distance between rows and the distance between plants in the row on the yield in bushels per acre of Cayuga soybeans, 1934 to 1937.*

Distance between plants in the row, inches	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
			1934		
½	—	—	32.9	32.4	29.8
1 or 1⅛	36.6	34.6	34.0	32.2	30.2
1⅓ or 1½	38.9	34.7	33.5	30.7	28.6
2 or 2¼	36.0	35.0	32.9	32.0	28.6
3	37.9	33.9	33.0	30.6	29.0
4 or 4½	37.4	34.6	33.3	30.9	27.4
6	37.2	32.1	31.1	29.2	—
			1935		
½	—	—	39.2	35.2	33.8
1 or 1⅛	42.8	38.5	40.0	36.8	32.9
1⅓ or 1½	43.1	39.7	37.4	36.5	31.2
2 or 2¼	44.8	38.3	37.7	34.2	28.1
3	41.3	38.2	36.0	29.9	26.8
4 or 4½	38.0	38.1	32.3	28.9	22.5
6	39.8	28.9	29.3	21.9	—
			1936		
½	—	—	32.9	31.8	28.4
1 or 1⅛	36.1	35.0	32.1	32.7	28.7
1⅓ or 1½	33.8	34.7	34.4	31.6	28.9
2 or 2¼	35.8	33.0	33.5	31.3	27.5
3	35.3	34.1	33.7	29.4	26.3
4 or 4½	33.2	32.6	30.8	28.7	25.4
6	34.7	33.8	30.7	26.4	—
			1937		
½	—	—	41.3	37.3	35.9
1 or 1⅛	44.9	39.8	39.7	38.0	32.6
1⅓ or 1½	44.4	39.0	37.4	36.2	29.9
2 or 2¼	42.7	39.8	32.9	32.4	23.0
3	43.8	35.5	32.8	26.7	21.8
4 or 4½	35.8	29.0	21.2	15.1	8.3
6	29.5	18.2	17.0	13.0	—

The data in this table show four points of special interest, (1) that yield decreases with any and all increases in the distance between rows; (2) that a wide range in the distance between plants in the row has little effect on the production, although there is always a tendency, with the exception cited above, for the yield to be greatest with the thickest planting, with a gradual falling off as the spacing increases; (3) that spacings greater than 3 inches within the row show significantly smaller yields than the thicker rates; and (4) that a yield of 40 bushels approaches the "ceiling" for this particular variety under the soil and climatic conditions existing in central New York.

The average of all the yields of the several spacings within the rows for the various widths of rows is shown in Fig. 1, by the solid line. The maximum yields for the several row widths are illustrated by the broken line at the top of the figure. Both these graphs show conclu-

sively that the yield decreases as the width of row increases. The same things might be shown with graphs made either from the yields of a given spacing within the rows of the various widths of rows or by the same total rate of seeding per acre where the spacing within the row is narrowed in proportion to the increase in the distance between rows.

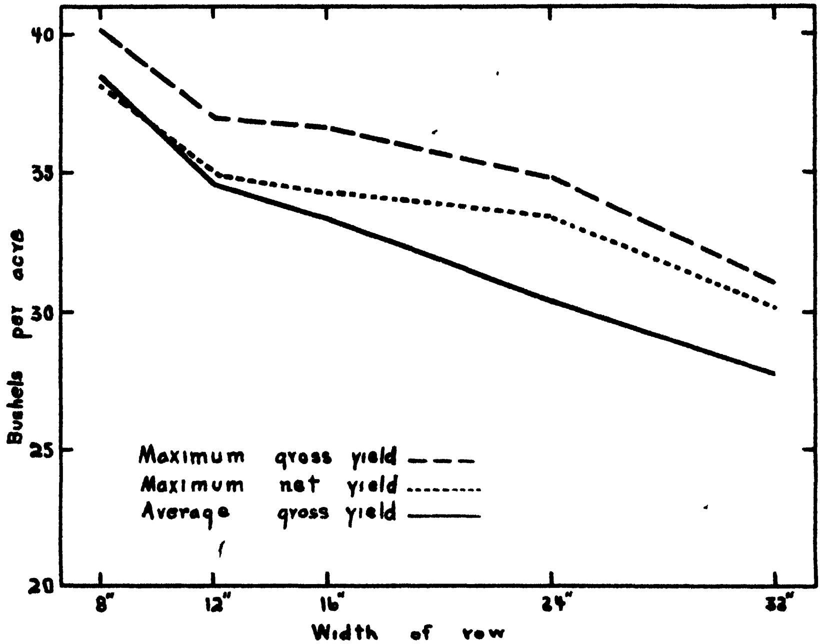

Fig. 1 —Showing the effect of the width of rows on the four-year average yield of Cayuga soybeans

FOUR YEARS AVERAGE NET PRODUCTION

The total or gross yield of soybeans in an experiment of this kind is not the final measure When wide differences in the rate of seeding are employed, the amount of seed used becomes a factor of considerable importance. In the lower half of Table 4 the net yields are given, which represent the total or gross production less the seed sown. Such a treatment of the data changes the picture to a considerable extent. The differences may be indicated as follows: (1) That the thickest plantings within the rows do not give the greatest returns, and (2) that the spacing within the rows giving the maximum yield varies with the width of row. This varies from 3 inches apart in the 8-inch rows to 1 inch apart in the 32-inch rows.

The maximum net yields for the various row widths is shown by the fine dotted line in Fig. 1. It will be noted that each of the three curves in this figure have the same general shape, showing the decline in yield with the widening of the rows. From these data it would seem reasonable to expect yields of rows with intermediate widths not

included in the experiments to fit closely into the curves as given in the figure.

EFFECT OF NUMBER OF PLANTS PER SQUARE FOOT OF AREA

The effect of the number of plants per square foot of area occupied is clearly shown in Table 5. The upper portion shows the gross and the

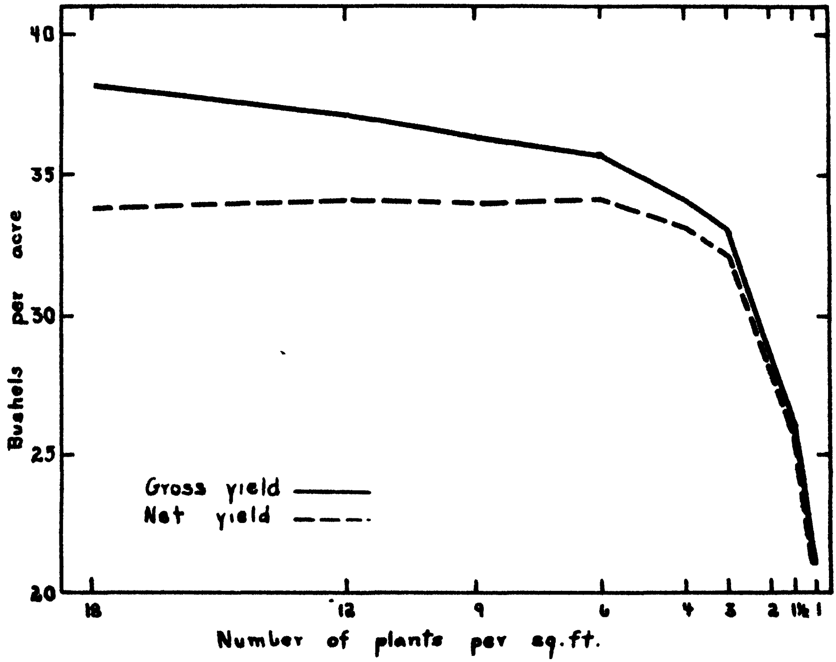

Fig. 2.—Showing the effect of the number of plants per square foot on the four-year average yield of Cayuga soybeans.

lower portion the net production. The maximum yields for the several row widths are indicated by asterisks. The average of the several arrangements of plants with a given number per square foot is shown graphically in Fig. 2, where the solid line represents gross and the broken line the net production. It is in the graph that the effect of the space given individual plants is best illustrated. There is a gradual falling off of gross yields from 18 to 6 plants per square foot, a much more rapid decline from 6 to 3 plants per square foot, and a precipitous drop from 3 plants to 1 plant per square foot

The net yield curve is decidedly different from the total or gross yield curve in that it not only shows a close approximation to a straight line curve but also a level curve from 18 to 6 plants per square foot. The curve from 6 plants to 1 plant per square foot is very similar to the curve for the total yield. The net results show no purpose in seeding at a rate beyond one which will give 6 plants per square foot, regardless of the method of distribution, except for compensation for possible losses in cultivation.

TABLE 4.—*Effect of the distance between rows and the distance between plants in the row on the yield in bushels per acre of Cayuga soybeans for a 4-year average.*

Distance between plants in the row, inches	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
Total or Gross Yield					
½	—	—	36.6 (*18*)*	34.2 (*12*)*	32.0 (*9*)*
1 or 1⅛	40.1 (*18*)*	37.0 (*12*)*	36.5 (*9*)	34.9 (*6*)	31.1 (*4*)
1⅓ or 1½	40.1 (*12*)	37.0 (*9*)	35.7 (*6*)	33.8 (*4*)	29.7 (*3*)
2 or 2¼	39.8 (*9*)	36.5 (*6*)	34.3 (*4*)	32.5 (*3*)	26.8 (*2*)
3	39.6 (*6*)	35.4 (*4*)	33.9 (*3*)	29.2 (*2*)	26.0 (*1½*)
4 or 4½	36.1 (*4*)	33.6 (*3*)	29.4 (*2*)	25.9 (*1½*)	20.9 (*1*)
6	35.3 (*3*)	28.3 (*2*)	27.0 (*1½*)	22.6 (*1*)	—
Net Yield (Total Production Less Seed Sown)					
½	—	—	32.1 (*18*)	31.2 (*12*)	29.7 (*9*)
1 or 1⅛	35.6 (*18*)	34.0 (*12*)	34.2 (*9*)	33.4 (*6*)	30.1 (*4*)
1⅓ or 1½	37.1 (*12*)	34.7 (*9*)	34.2 (*6*)	32.8 (*4*)	28.9 (*3*)
2 or 2¼	37.5 (*9*)	35.0 (*6*)	33.3 (*4*)	31.7 (*3*)	26.3 (*2*)
3	38.1 (*6*)	34.4 (*4*)	33.1 (*3*)	28.7 (*2*)	25.6 (*1½*)
4 or 4½	35.1 (*4*)	32.8 (*3*)	28.9 (*2*)	25.4 (*1½*)	20.6 (*1*)
6	34.5 (*3*)	27.8 (*2*)	26.4 (*1½*)	22.3 (*1*)	—

*Number plants per square foot indicated by figures in parenthesis.

TABLE 5.—*Effect of the number of plants per square foot on the yield in bushels per acre of Cayuga soybeans for an average of four years.*

Plants per square foot	Distance between rows				
	8 in.	12 in.	16 in.	24 in.	32 in.
Total or Gross Yield					
18	40.1*	—	36.6*	—	—
12	40.1*	37.0*	—	34.2	—
9	39.8	37.0*	36.5	—	32.0*
6	39.6	36.5	35.7	34.9*	31.3
4	36.1	35.4	34.3	33.8	31.1
3	35.3	33.6	33.9	32.5	29.7
2	—	28.3	29.4	29.2	26.8
1½	—	—	27.0	25.9	26.0
1	—	—	—	22.6	20.9
Net Yield					
18	35.6	—	32.1	—	—
12	37.1	34.0	—	31.2	—
9	37.5	34.7	34.2*	—	29.7
6	38.1*	35.0*	34.2*	33.4*	29.8
4	35.1	34.4	33.3	32.8	30.1*
3	34.5	32.8	33.1	31.7	28.9
2	—	27.8	28.9	28.7	26.3
1½	—	—	26.6	25.5	25.6
1	—	—	—	22.3	20.6

*Maximum yields.

CONCLUSIONS

The results for four years of varying rates of seeding of Cayuga soybeans as influenced both by the spacing within the row and the width between the rows lead to the following general conclusions. The specific conclusions directly applicable to early-maturing soybean varieties as represented by Cayuga were presented above as the experimental results were discussed.

1. The nearer the arrangement of plants on a given area approaches a uniform distribution, the greater will be the yield. Other things being equal, the narrower the distance between rows until the distance between rows equals the space between plants in the row, the greater the yield.

2. Within wide ranges the number of plants per square foot of area has little effect on net increases. There is nothing to be gained by seeding beyond a given optimum.

3. The soybean plant, like many others, has the ability to make wide adjustments to space.

4. Optimum rates and spacings for soybeans should be determined not only for the various soybean-producing areas but also for the varieties to be grown. Large-growing, late-maturing varieties would hardly be expected to require the same rate or spacing for optimum yields that small-growing, early-maturing varieties require.

5. A variety of soybeans has an optimum number of plants per unit area for the maximum net increase. For Cayuga this rate is 6 plants per square foot.

SOME FACTORS AFFECTING THE PREVALENCE OF WHITE CLOVER IN GRASSLAND[1]

B. A. BROWN[2]

WHITE clover (*Trifolium repens*) is the most important legume found in the permanent grassland of the northeastern United States. As shown by several investigators (1, 4, 5, 7, 9, 10),[3] grassland with a considerable proportion of its area occupied by white clover yields much more than grass alone, and frequently as much or more than can be stimulated by the addition of large amounts of nitrogenous fertilizers. Not only are total yields greatly enhanced, but the palatability, nutritive value, and the seasonal distribution of the pasturage are improved by white clover. It is, therefore, of much economic importance that permanent grassland be managed so as to assure this legume a prominent place in the sward It should be admitted, however, that in spite of the widespread interest in and amount of research with white clover, no one knows the reasons for the amazingly sudden changes in its prevalence

During the nearly 20 years of pasture research at the Storrs, Conn., Agricultural Experiment Station, there have accumulated many data pertaining to factors affecting the prevalence of white clover. Although these results have not led to definite conclusions, it seems advisable to publish them at this time

An important factor affecting the prevalence of white clover, but one on which the author has few data, is that of soil type. All of the experiments reported in this paper were conducted on Charlton fine sandy loam soil. This soil is well adapted for grasses and clovers if provided with the proper fertilizers.

Most of the lawn mowing in these experiments has been done with a roller driven type of power mower.

WHITE CLOVER AND YIELDS OF GRASSLAND

The importance of white clover to yields of grassland is indicated by the data in Table 1, which summarizes this Station's results on that subject when only volunteer clover is concerned.

Under either grazed or lawnmowed conditions, production was 5 to 10% higher with PKL than PKN fertilization when clover occupied 30% or more of the area. The reverse was true when the area with clover fell to 10% or less.

The effects of seeding Ladino or Kent[4] white clover on plats of nine grasses in pure culture and also of fertilizing these grasses with varying amounts of nitrogen are shown in Table 2. In this experiment, seeding Ladino clover resulted in more dry matter than adding nitro-

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Also presented at the meeting of the American Society of Agronomy, Washington, D. C., November 16–18, 1938. Received for publication December 29, 1938.

[2]Associate Agronomist.

[3]Reference by number is to "Literature Cited", p. 332.

[4]Strain of white clover indigenous in old, closely grazed pastures of Kent County, England.

TABLE 1.—*Yields and prevalence of white clover.*

Period	Relative yields		Area occupied by clover, %†	
	PKL*	PKN*	PKL	PKN
	Cut with Lawnmower‡			
1932-35	100	91	38	7
1936-37	100	128	4	1
	Grazed§			
1924-28	100	95	65	38
1932-37	100	114	9	5

*P = superphosphate, K = muriate of potash, L = ground limestone, and N = nitrogenous fertilizers.
†Estimated from inspection.
‡Field D, treatment No 30 vs treatment No 8 (averages of six plats).
§Cummings pasture, plat 8N vs plats 9N and 9S.

gen at 84 pounds annually. The Kent clover plats outyielded the unfertilized ones by a wide margin, although the latter had large amounts (over 30%) of volunteer white clover, and also produced more pasturage than N1 fertilization.

TABLE 2.—*White clovers and yields of grassland.*

Treatment*	Dry matter per acre, lbs.†		
	1936	1937	Total
Kent clover seeded	2,005	2,857	4,862
Ladino clover seeded	3,481	3,493	6,974
No	1,584	2,626	4,210
N1	1,911	2,871	4,782
N12	2,295	2,924	5,219
N123	2,707	3,170	5,877

*The clovers were seeded at 5 pounds in March, 1936, without tillage, on surface of plats of grasses planted in August, 1935. N equals nitrogen at 28 pounds from Calnitro. The figures after the letter N refer to time of application: No, none, N1, April, N12, April and June, and N123, April, June, and August. Thus, N123 means a total of 84 pounds in three applications.
†Average of nine grasses on R3 seeded in pure culture in August, 1935.

SOURCE OF SEED

Practically all of the white clover in the permanent pastures throughout the world has volunteered and is, of course, of unknown origin. Selection of individual plants from such habitats has demonstrated the presence of many widely varying types or strains. The predominating type is the one best adapted for the environment resulting from the management of any given pasture. There are, also, great variations in the climates of the regions where white clover seed is produced and this may influence its longevity, especially when planted in areas with more rigorous weather conditions.

Twelve strains of white clover[5] were planted in the spring of 1936 on 50- by 6-foot plats. In the spring of 1937, nine strains of white clover, including five not in the 1936 tests, were sown on triplicated,

[5]E. A. Hollowell of the U. S. Dept. of Agriculture kindly cooperated by furnishing seed of most of the white clover strains.

40- by 6-foot plats, located on another field. In the first case, the clovers were seeded at 18 pounds with commercial Kentucky bluegrass at 100 pounds per acre. In the second instance, the clovers were seeded at 2 pounds and Kentucky bluegrass at 24 pounds. In both cases, the plats were cut to 1 inch above the soil with a lawnmower when the vegetation reached a height of 3 to 4 inches.

The stands of these clovers are given in Tables 3 and 4. The data show a very strong tendency for the strains indigenous in old pastures of several countries to maintain better stands than the others. In this respect, the Danish, Polish, and commercial white Dutch clovers were among the poorest. The strains from several states of the United States were intermediate and, to date, there appear to be no significant differences between southern, northern, and far western sources. The commercial strains flowered much more profusely than any of the others. This suggests selection for seed bearing rather than for vegetative growth or longevity.

TABLE 3.—*Source of white clover seed and longevity.**

Source of seed†	Area occupied by clover, %‡			
	Oct., 1936	Oct., 1937	May, 1938	Aug., 1938
Denmark	50	2	5	5
Poland	95	5	10	15
Idaho	85	10	10	15
Denmark ("Morso")	70	6	10	15
New York, old pasture	80	10	15	20
Oregon	80	3	5	25
Missouri	65	10	15	20
England (Cotswold native)	60	35	25	30
New Zealand ("virgin")	90	30	20	40
England (E. Anglia native)	80	40	40	55
New Zealand (native)	80	25	30	60
England (Kent old pasture)	75	35	40	65

*Field R4; Seeded spring of 1936.
†"Native" refers to "wild" strains.
‡Estimated from inspection.

TABLE 4.—*Source of white clover seed and longevity.**

Source of seed†	Area occupied by clover Sept., 1938, %‡
Volunteer	7
Commercial white Dutch	8
Poland	15
Oregon	17
Wisconsin	21
Louisiana	25
Illinois	29
Mississippi	38
England (Kent old pasture)	45
New York (native)	57

*Field T; seeded spring of 1937 with Kentucky bluegrass.
†"Native" refers to "wild" strains.
‡Estimated from inspection.

CLIMATIC CONDITIONS

The marked prevalence of white clover in the so-called *clover* years has been ascribed by some writers to the weather. No doubt some climatic factors are important, but the clover readings since 1922 on the series of grazed pastures at Storrs, Conn., indicate that the weather has been over-emphasized. As may be noted in Table 5, remarkable increases in clover occurred on two occasions, many years apart, both during the two growing seasons immediately following the *first* application of P to pastures where the soil was very deficient in that element. Repeating the P at 3- to 5-year intervals has not maintained or brought back the clover to the high levels obtained soon after the initial applications The competition of the grasses, greatly thickened and invigorated by fertilizers and association with clover, appears to be much more potent than any weather factor experienced in this locality. This supposition is supported by results presented below.

TABLE 5.—*The relative effects of climate and fertilization on the prevalence of white clover.**

Year	Area occupied by white clover, %†		Area occupied by grasses, %†	
	First P in 1924	First P in 1932	First P in 1924	First P in 1932
1922	9	10	-	—
1925	63	9		-
1932	11	1	71	47
1933	10	70	—	—
1936	7	40	—	
1937	6	10	74	74
1938	21	17	54	67

*Cummings pasture grazing experiment, plats 1N and 8N vs 3W All of these plats also received limestone and 8N and 3W also received potash

†Estimated from inspection

SPECIES OF GRASSES

During the early spring of 1936, six treatments were initiated on duplicate 8- by 50-foot plats on each of nine common grasses seeded in pure culture the previous August. The nine grasses in this experiment were: Kentucky bluegrass (*Poa pratensis*), Canada bluegrass (*Poa compressa*), Rhode Island bent (*Agrostis tenuis*), timothy (*Phleum pratense*), orchard (*Dactylis glomerata*), perennial rye (*Lolium perenne*), smooth brome (*Bromus inermis*), meadow fescue (*Festuca pratensis*), and tall oat (*Arrhenatherum elatius*). The six treatments were Kent white clover seeded; Ladino clover seeded; and No, N1, N12, and N123 fertilization (see Table 2 for explanations of symbols). The clovers were sown at the rate of 5 pounds in March on the surface without tillage. Calnitro was the source of nitrogen. The soil had a pH of 5.6 and was well supplied with P and K.

Since about May 1, 1936, the vegetation has been harvested when about 4 inches high with a motor lawnmower, set to cut to 1 inch above the soil. From 6 to 11 cuttings have been made each year. All clippings have been removed from the plats.

The Kent and Ladino clovers had excellent stands by midsummer of the year of seeding (1936). During the last part of the 1936 season and most of the 1937 season, Ladino clover grew so thickly and rapidly that a casual inspection would not have revealed the presence of the grasses. Native clover soon volunteered and under the No treatment occupied nearly as much area as Ladino and Kent clovers did on their respective plats. Estimates of the area in clover have been made for each plat twice each season. For the purpose of showing in a brief form the marked effects of type of grass on the prevalence of white clovers, the nine grasses have been divided into three groups, as follows. (a) The bluegrasses and bent grasses which maintain good stands when cut with a lawnmower; (b) timothy, orchard, and perennial rye grasses, which had poor to fair stands during the three years in question; (c) brome, meadow fescue, and tall oat grasses, which had very poor stands soon after starting the lawnmowing The average stands of clover in 1937 and 1938 for these three groups of grasses are shown in Table 6.

TABLE 6.—*Effects of species of grasses and nitrogenous fertilizers on the prevalence of white clover.**

Treatment†	Area occupied by white clover, %‡		
	With Kentucky bluegrass, Canada bluegrass and bent	With orchard, perennial rye and timothy	With tall oat, brome, and meadow fescue
Kent seeded	41	51	75
Ladino seeded	33	45	59
No . .	35	50	67
N1	23	41	68
N12	17	37	65
N123	13	29	62
Average	27	42	66

*The values in this table are the averages of clover stands for two readings for each grass on R3 in both 1937 and 1938

†No means no N; N1, April N, N12, April and June N, and N123, April, June, and August N Each application supplied N at 28 pounds, all from Calnitro

‡Estimated from inspection

From a study of Table 6, it is readily apparent that the competition afforded by the different types of grasses had very marked effects on the prevalence of the clovers. This is true regardless of seeding or application of N It is obvious that the degree of retardation of clover by N depends on the amounts of the accompanying grasses present to utilize the N For example, with no N there was about half as much clover with the bluegrass-bent group as with the brome-tall oat-fescue group of grasses, but under N123 fertilization the corresponding value was one-fifth.

Blackman (2) found that ammoniacal N appeared to have a toxic effect on white clover. In the Storrs experiment, Calnitro was the source of N. About one-half of the N in Calnitro is in the ammoniacal form, yet in the case of grasses with very poor stands, applying that fertilizer at 140 pounds per acre three times each season for 3 years has decreased the clover only from 67 to 62%. These results strongly

indicate that the indirect effects of N, by increasing the competition of grasses, are far more important than any direct effects. Of course, salts like $(NH_4)_2SO_4$, which have a strong acidifying effect on the soil, may in a short time change an already acid medium to a reaction entirely unsuitable for clover Some unpublished data show that this is especially true of surface applications.

Further evidence regarding the important effects of kind of grass on the prevalence of white clover is furnished by another experiment in which Ladino and Kent clovers were seeded at 2 pounds in triplicated 40- by 6-foot plats with each of several grasses Harvesting has been similar to that in the experiment discussed above At the end of the second season, there was three times as much Ladino and twice as much Kent clover with perennial rye as with Rhode Island bent grass (Table 7)

TABLE 7 *Effects of different grasses on prevalence of white clover.**

Species of grasses seeded	Area occupied by clover, %†	
	Ladino seeded	Kent seeded
Rhode Island bent	21	28
Kentucky bluegrass	33	45
Kentucky bluegrass and Rhode Island bent	23	41
Kentucky bluegrass and timothy	38	25
Orchard	46	37
Orchard and timothy	57	40
Timothy	72	45
Meadow fescue	72	50
Perennial rye	72	55

*Field T, seeded spring 1937, clover readings of Sept, 1938
†Estimated from inspection

SOIL FERTILITY AND FERTILIZATION

In northeastern United States, one of the first visible effects of mineral fertilizers on run-down pastures has been the pronounced spread of native white clover Later the better grasses usually have become dominant and this has been accompanied by a marked reduction in clover. It is important to learn which, if any, methods of fertilizing will maintain a large (over 30% of the area) amount of clover in the turf. The Storrs Experiment Station has two experiments which furnish some evidence on this point. One is the grazing project with 17 2-acre pastures; the other is contiguous to the first and contains over 100 duplicate 50- by 20-foot plats on a long untilled meadow cut in June for hay and grazed during the late summer and fall.

In both cases, the untreated soil is acid (pH 5.2) and very deficient in easily soluble P The fertilizers have been applied on the surface and there has been no seeding or tilling for 25 years at least

The more recent estimates of native white clover in the grazed pastures are given in Table 8. It is now 14 years since the first fertilizers were applied to those pastures and 6 years since any changes were made in the schedule. Since 1928, rotational heavy grazing with yearling steers or heifers, receiving no supplemental feed, has been

the practice. Therefore, the values in Table 8 represent the response of white clover to long-continued, exact treatments under actual grazing conditions.

TABLE 8.—*Fertilization of grazed pastures and the prevalence of white clover.*

General treatment*	Area occupied by white clover			
	Oct., 1937	June, 1938	Sept., 1938	Average
No P	1	1	3	2
P	3	5	10	6
PL	9	14	21	15
PLK	9	17	26	17
PK	6	13	11	10
PKN1 or N2 or N3	4	7	11	7
PLKNN1	2	-	10	6
PLKN12 or N23	4	—	14	9
PLKN123	2	1	11	5

*P = superphosphate to supply P_2O_5 at 400 pounds per acre from 1924 to 1938, K = muriate of potash to supply K_2O at 250 pounds per acre from 1924 to 1938, L = limestone at 4,000 pounds per acre from 1924 to 1938, N = nitrogen at 28 pounds per acre at each application, and NN = nitrogen at 56 pounds per acre at each application. The numbers after the letters N or NN refer to time of application of nitrogen: 1 means April, 2, June, and 3, August applications. N123 means a total of 84 pounds in three applications. The nitrogen was supplied by a mixture of 200 pounds of sulfate of ammonia and 100 pounds of nitrate of soda through 1934 and since then entirely by Calnitro.

It is readily apparent that without the addition of P there was very little clover. There have been appreciable proportions of clover with superphosphate alone, but over twice as much when limestone was included with the superphosphate. Potash, either with superphosphate or superphosphate and limestone, has made clover somewhat more prominent, the complete minerals (PLK) resulting in the most clover.

Nitrogen, supplied since 1935 in the neutral carrier, Calnitro, has kept the percentages of clover very low until 1938, when, in common with most of these pastures, one of those marked inexplicable increases occurred between June and September. As most of the grass population is composed of the turf-forming species, Kentucky bluegrass and Rhode Island bent, and in view of the data, presented in previous pages, showing how effective these grasses are in reducing white clover in mixed stands, it is concluded that the effects of the N have been chiefly indirect, that is, in increasing the competition of the grasses.

The second experiment to be considered here was started in 1930 on a meadow run out by the long removal of hay without any fertilization. For the sake of brevity, only the averages of clover readings for groups of treatments, such as several N or P carriers or time of adding fertilizers, are given in Table 9.

It is evident that on this field P or L alone or together have not been very influential in promoting the advent of clover. In contrast to the nearby grazing experiment, the addition of potash, with either P or PL, has resulted in a very pronounced increase in clover. Probably the great response to potash here was due to the long-continued removal of hay, *viz.*, run out by mowing rather than by grazing. Where potash was applied in April 1937 for the first time, even larger

TABLE 9.—*Fertilization of hay land and prevalence of white clover.**

Fertilization†	Area occupied by white clover, %‡			
	June, 1936	Sept., 1937	May, 1938	Average
L	4	4	1	3
P	8	4	4	5
PK	12	18	17	16
LP	4	4	5	4
LPK	12	25	23	20
LPK (First K in 1937)	7	40	37	28
LPKN	12	20	21	18
LM	21	22	21	21
LMP	37	30	39	35
All L plats	13	21	20	18
All LP plats	14	23	22	20
All LPK plats	12	24	22	19
All M plats	29	26	30	28

*This land has been mowed for hay in June and grazed periodically in late summer and fall

†L = limestone at 4,000 or more pounds per acre since 1930, P = phosphorus carriers to supply at least 300 pounds per acre of P_2O_5 since 1930, K = muriate of potash to supply at least 200 pounds per acre of K_2O since 1930, N = nitrogen carriers to supply at least 30 pounds per acre of N annually since 1930, and M = manure at 5 tons per acre annually, or 10 tons biennially, since 1930

‡The results of several treatments, differing only in N or P carrier or time of application, have been grouped in this table Areas estimated from inspection

amounts of clover were present in September 1937 and May 1938. Again this is considered due to the thinner stand of grasses where little clover had grown previous to 1937

The average results of several carriers and times of application of N show little reduction in clover from the N However, some of the N plats, particularly those receiving a large amount at one time in either April or June, have had very rank grass and little clover.

The most clover has occurred on the plats fertilized with limestone, superphosphate, and manure. The reasons for the very beneficial effects of manure have not been determined, although carriers of many minor elements have been added to other plats of clover to learn if one or more might be of value. In this case, manure may owe its superiority to the additional potash supplied by 5 tons each year. On a similar soil, this has been found to be true of alfalfa.

MANAGEMENT

Some investigators have found the date, frequency, and closeness of grazing or mowing to be very influential on the prevalence of white clover (6, 7, 8). Very close and frequent grazing or mowing, especially during May and June, when grasses make their most rapid growth in the north temperate zone have favored certain types of white clover. It was under such conditions that the Kent old pasture strain of clover developed in the Romney Marsh district of England. Management to promote large proportions of white clover in pastures usually favors the extremely low-growing types which are not entirely defoliated by close grazing. That this kind of management is not always necessary for *all* types is shown by the large amounts of vol-

unteer, native white clover maintained for several years on the series of hay plats discussed in the preceding section of this paper.

At the Storrs Experiment Station, the Ladino variety of white clover has maintained much better stands under more lenient systems of cutting. For example, it has been almost entirely eradicated from some Kentucky bluegrass-Ladino clover plats by two seasons of lawnmowing (cut *when* 3 or 4 inches *to* 1 inch), but has spread into and now constitutes nearly 100% of the stand on adjacent hay land where there had been no seeding of Ladino Several experiment stations have found Ladino to be much more productive than other varieties of white clover It is of considerable importance, therefore, to learn the best methods of managing land seeded with this legume Although far from complete, the experiments at Storrs, where Ladino has been cut by lawnmowers and mowing machines and also grazed in different ways, indicate that an average of about one cutting or grazing per month and not shorter than 2 inches above the soil will give the best results over a period of 3 years or more.

One season's cutting of Ladino to ½ inch reduced its stand appreciably. This was true also of Kent clover when seeded with Kentucky bluegrass. In the case of the Cornell 1937 seed mixture, the ½ inch cutting did not decrease the amount of clover, probably because less Kentucky bluegrass, a very competitive turf-forming species, was seeded in that mixture. These data are summarized in Table 10.

TABLE 10 —*Effects of cutting white clovers to different heights* *

Mixture seeded	Area occupied by clover, Sept 1938, %†	
	Cut to 1 inch	Cut to 0 5 inch
Cornell 1937	43	50
Kentucky bluegrass and Ladino	33	20
Kentucky bluegrass and Kent	45	23

*Field T; seeded spring of 1937, but only subjected to different cuttings in 1938 Cut when 4 inches high

†Estimated from inspection

The average amounts of volunteer native white clover found in 1934 and 1935 in Kentucky bluegrass and Rhode Island bent grass plats under four different fertilizer treatments and four frequencies of cutting since 1932 are given in Table 11 The soil had a reaction of pH 6.0 and was well supplied with P and K. Under those conditions, there was a tendency in all cases for the clover to increase with less frequent mowing Regardless of height when cut, the N123 fertilization reduced very markedly the amounts of clover.

In concluding this section on management of experimental plats, the writer takes the opportunity to express again the opinion that standardization in methods of performing certain experimental work may defeat the very purpose of the experiment. This danger arises because any given culture may or may not give its best or even a mediocre response under any specific practice. Thus, using the same management for evaluating the worth of all species and varieties of grasses or legumes might be likened to deciding on all men's fitness for all kinds of work by their knowledge of a single subject.

TABLE 11.—*Frequency of cutting Kentucky bluegrass and Rhode Island bent grass plats and prevalence of volunteer native white clover.*

Fertilization*	Percentage of area occupied by white clover,† plats lawnmown when vegetation reached height of			
	2 in.	3 in.	4 in.	5 in.
No	21	23	29	34
N1	21	20	26	26
N12	17	16	18	21
N123.	7	5	7	13
Averages	17	16	20	24

*No = no nitrogen, N1 = nitrogen at 28 pounds in April, N12 = nitrogen at 28 pounds in April and June; and N123 = nitrogen at 28 pounds in April, June, and August The nitrogen was from a mixture of 200 pounds of sulfate of ammonia and 100 pounds of nitrate of soda

†Estimated from inspection

SUMMARY

The causes of the wide fluctuations in the prevalence of white clover (*T repens*) in grassland are still largely undetermined. The results at many experiment stations have shown the importance of having large percentages of white clover in permanent grasslands. These findings are supported by results at the Storrs, Conn., Agricultural Experiment Station

Over a 3-year period, strains of clover, indigenous in old pastures of England, New Zealand, and the United States, have maintained the best stands in grass-clover seedings Polish, Danish, and commercial white Dutch were the shortest lived of 18 strains. In respect to longevity, there appeared to be little choice between seed from northern, southern, or far western parts of the United States.

Climatic conditions have been of less importance than fertilization or species of grasses in the maintenance of white clover in mixed stands.

Clover has been much less prevalent with the turf-forming grasses, such as the bluegrasses and bents, than with species having more open stands.

The retarding effects of nitrogenous fertilizers on clover in grassland were due chiefly to the increased grass competition caused by the nitrogen.

In grazed permanent pastures, very little clover has been present without adding phosphorus. Pastures with complete minerals (PLK) had the most clover, but omission of K had little effect. In the case of an adjacent permanent meadow mowed in June for hay and grazed in late summer and fall, adding either potash or manure with superphosphate and limestone was very influential in promoting large amounts of clover.

On Charlton fine sandy loam soil, minor elements have had no appreciable effects on clover.

Lawnmowing to ½ inch for one season greatly decreased both Ladino and Kent clovers in Kentucky bluegrass-clover seedings, but Kent clover increased slightly under this management in a mixture

with less bluegrass. Cutting to 1 inch was the standard of a comparison.

The amounts of volunteer white clover increased with height when vegetation was mowed during 4 years under four different methods of fertilizing Kentucky bluegrass and Rhode Island bent grasses, cut when 2, 3, 4, and 5 inches in height.

In grassland research, the writer feels that the use of a standardized or single method may defeat the purpose of many experiments.

LITERATURE CITED

1. BEAUMONT, A. B. Experiments with permanent pastures. Mass. Agr. Exp. Sta. Bul. 281. 1932.
2. BLACKMAN, G. E. The ecological and physiological action of ammonium salts on the clover content of turf. Ann. Bot., 48:975-1001. 1934.
3. BROWN, B. A. Technique in pasture research. Jour. Amer. Soc. Agron., 29: 468-476. 1937.
4. FERGUS, E. N. The place of legumes in pasture production. Jour. Amer. Soc. Agron., 27:367-373. 1935.
5. GARDNER, F. D., *et al.* Pasture fertilization. Pa. Agr. Exp. Sta. Bul. 323. 1935.
6. HEIN, M. A., and COOK, A. C. Effect of method and rate of grazing on beef production and plant population of pastures at Beltsville, Md. U. S. D. A. Tech. Bul. 538. 1937.
7. JOHNSTONE-WALLACE, D. B. The influence of grazing management and plant associations in the chemical composition of pasture plants. Jour. Amer. Soc. Agron., 29:441-455. 1937.
8. JONES, MARTIN G. Grassland management and its influence on the sward: II. The management of a clovery sward and its effects. Empire Jour. Exp. Agr., 1:122-127. 1933.
9. PRINCE, FORD S., BLOOD, PAUL T., and PERCIVAL, G. P. Topdressing old pastures. N. H. Agr. Exp. Sta. Circ. 35. 1931.
10. ROBINSON, R. R., and PIERRE, W. H. Response of permanent pastures to lime and fertilizers (1930-1936). W. Va. Agr. Exp. Sta. Bul. 289. 1938.

SUSCEPTIBILITY OF SEEDLING GRASSES TO DAMAGE BY GRASSHOPPERS[1]

WILFORD HERMANN AND ROBERT ESLICK[2]

A PORTION of the grass nursery of the Division of Agronomy, Washington Agricultural Experiment Station, containing 405 selections from 28 species, was seeded in 9-foot rows 2 feet apart on April 11, 1938. The rows were thinned to a 1-inch spacing between May 15 and May 20 and to approximately an 8-inch spacing between July 15 and July 20. Although precipitation was deficient during the spring and early summer months, the grasses made a good growth and those not displaying the winter habit were blooming at the time of the second thinning.

On August 1 strong southwest winds brought large numbers of grasshoppers into the nursery In all, 187 grasshoppers were caught and identified as to genus and, where possible, as to species (Table 1).[3] Of those examined, 153 were mature grasshoppers and 34 were nymphs. Four species of grasshoppers were found. One hundred ten, or 58.8%, of the insects proved to be the Warrior grasshopper, *Camnula pellucida* Scudd., and the remainder were species of the genus Melanoplus. It is believed that *C. pellucida* was the species observed migrating into the nursery. The Melanoplus species probably developed close to or in the nursery as many of these were observed around the plats previous to the immigration.

TABLE 1.- *Grasshopper species observed in the 1938 grass nursery at Pullman, Washington.*

Grasshopper species	Number	%
Camnula pellucida Scudd	110	58.8
Melanoplus mexicanus Sauss	20	10.7
Melanoplus femur-rubrum De G	17	9.1
Melanoplus bivittatus Say	6	3.2
Melanoplus spp. Stal. (Nymphs)	34	18.2
Total	187	100.0

The species of grasshoppers observed in the Pullman nursery consisted of four of the five reported by Shotwell (6)[4] who found that the most important species of grasshoppers in the crop areas of the North Central States were *Melanoplus bivittatus* Say., *M. differentialis* Thos., *M. femur-rubrum* De G., *M. mexicanus* Sauss., and *Camnula pellucida* Scudd. He observed that the proportions of these species varied from year to year with no individual species maintaining con-

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[3]The authors wish to thank R. D. Eichmann, Assistant Entomologist, Division of Zoology, Washington Agricultural Experiment Station, for his assistance in identifying the grasshoppers.

[4]Numbers in parenthesis refer to "Literature Cited", p. 336.

tinued dominance. In areas utilized chiefly for range purposes, Shotwell reported that Melanoplus and Camnula species were replaced by *Ageneotettix deorum* Scudd., *Encoptolophus sordidus* Burm., *Trachyrachis kiowa* Thos., *Aulocara elliotti* Thos., and others of lesser significance. In all, 30 species of grasshoppers were reported to have economic importance.

Parker, Walton, and Shotwell (5), summarizing grasshopper information, listed the grasshoppers included in this paper as some of the most important in the United States.

Strand (7) placed the damage done to the ranges of Montana by grasshoppers at $1,750,000 for the period 1934-36. The most important species were *Aulocara elliotti* Thos., *Melanoplus mexicanus* Sauss., and *Camnula pellucida* Scudd., respectively. Strand observed that these species attack cultivated crops as well as grasses.

The reports of these investigators indicate that the species of grasshoppers observed in the grass nursery at Pullman are widespread over the north-central portions of the United States.

Observations previous to August 1 indicated that damage to the seedlings by grasshoppers was negligible. After the appearance of the insects in large numbers evidence of damage to the seedlings became rapidly apparent. Nine days (August 9) after the appearance of the immigrant grasshoppers, notes on damage were taken by the authors. The percentage of damage sustained by each selection was determined by estimation of the proportion of the leaves destroyed. Estimations were made independently by the authors and on only three selections was there a disagreement of greater than 10%. These estimations are summarized in Table 2.

Subsequent observations by the authors revealed no changes in the comparative or total amounts of damage sustained by the different species and selections. The spreading of poison bran by members of the Divisions of Agronomy and Entomology on the morning of August 10 resulted in a 60 to 70% kill which probably accounts for the check in the damage done to the seedling grasses.

Tabulation of the notes on damage showed that the species of grasses varied significantly in susceptibility to grasshopper attacks. Five species, *Bromus mollis* L., *Deschampsia elongata* (Hook.) Munro., *Festuca idahoensis* Elmer., *Festuca ovina* L., and *Festuca rubra* var. *commutata* Gaud., displayed complete defoliation from attack by grasshoppers. Ten species, *Agropyron cristatum* (L.) Gaertn. (Standard variety), *Agropyron elongatum* (Host) Beauv., *Agropyron repens* (L.) Beauv., *Agropyron subsecundum* (Link.) Hitchc., *Arrhenatherum elatius* (L.) Mert. and Koch., *Dactylis glomerata* L., *Elymus glaucus* Buckl., *Festuca elatoir* L., *Hordeum bulbosum* L., and *Poa secunda* Presl., showed an average of between 80 and 100% defoliation by grasshoppers. Four species, *Agropyron smithii* Rydb., *Bromus inermis* Leyss., *Elymus canadensis* L., and *Phalaris arundinacea* L., showed an average damage of less than 20% for each species. The other species were intermediate in susceptibility to grasshopper damage. Similar differential feeding of grasshoppers on species of graminaceous crops has been observed in areas where corn and sorghum were grown in adjacent fields (2).

TABLE 2 —*Injury caused by grasshoppers feeding on the foliage of seedling grasses*

Grass species	Habit of growth	No of selec-tions	Range of damage, %*	Average damage, %*
Agropyron cristatum (L) Gaertn (Fairway)	Spring	23	50 80	69
Agropyron cristatum (L) Gaertn (Standard)	Spring	68	30 100	82
Agropyron elongatum (Host) Beauv	Winter	1	— —	80
Agropyron inerme (Scribn & Smith) Rydb	Spring	41	20 95	74
Agropyron pauciflorum (Schwein) Hitchc	Spring	49	10 80	35
Agropyron pauciflorum (Schwein) Hitchc	Winter	4	50 90	78
Agropyron repens (L) Beauv	Winter	3	70 90	83
Agropyron smithii Rydb	Winter	1		5
Agropyron spicatum (Pursh) Scribn & Smith	Spring	21	40 90	69
Agropyron subsecundum (Link) Hitchc	Winter	2		90
Arrhenatherum elatius (L) Mert & Koch	Spring	5	70 90	82
Bromus inermis Leyss	Winter	40	5 50	19
Bromus marginatus Nees	Spring	8	10 70	45
Bromus mollis L	Winter	1		100
Bromus polyanthus Scribn	Spring	16	10 90	64
Dactylis glomerata L	Winter	17	50 95	80
Deschampsia elongata (Hook) Munro	Winter	1		100
Elymus canadensis L	Spring	2	5 10	8
Elymus condensatus Presl	Winter	3	20 50	30
Elymus glaucus Buckl	Spring	22	60 100	82
Festuca elatior L	Winter	5	75 90	87
Festuca idahoensis Elmer	Winter	13		100
Festuca ovina L	Winter	5	—	100
Festuca rubra var *commutata* Gaud	Winter	10		100
Hordeum bulbosum L	Winter	1	—	95
Phalaris arundinacea L	Winter	15	0 40	8
Poa ampla Merr	Spring	10	50 90	76
Poa nevadensis Vasey	Spring	6	40 80	60
Poa secunda Presl	Winter	3	90 100	97
Secale cereale L × *Secale montanum* Guss	Winter	9	40 90	72

*Damage represents an estimation of the proportion of leaves destroyed by grasshoppers

The Standard variety of *Agropyron cristatum* (L) Gaertn was damaged considerably more than the Fairway variety even though the latter has a finer and more leafy growth Similar differences in damage by grasshoppers have been reported for dent and flint corn (3) and for sorgo, kafir, and milo sorghums (2)

Among species, habit of growth, i e , winter entirely vegetative, or spring first-year flowering, had slight, if any, influence upon their respective susceptibilities Within a species, however, the selections with the winter habit of growth displayed a greater susceptibility toward grasshopper damage than those with the spring habit of growth. This differential susceptibility of the varying growth habits was best illustrated by *Agropyron pauciflorum* (Schwein) Hitchc in which those selections with the winter habit showed 78% damage while those with the spring habit showed only 35% damage Apparently those selections with the spring habit of growth were more nearly in a mature stage than in a seedling stage of development. Consequently, observations of these plants may approximate the susceptibility of mature plants rather than the susceptibility of seedlings.

Selections within each species displayed wide differences in comparative susceptibility to damage by grasshoppers. Of those species from which over 10 selections had been made, only *Festuca idahoensis* Elmer. and *Festuca rubra* var. *commutata* Gaud. failed to display selection differences in susceptibility to attack by the insects. These two species were completely susceptible. On the other extreme were *Bromus polyanthus* Scribn., *Agropyron cristatum* (L.) Gaertn. (Standard), *Agropyron inerme* (Scribn. and Smith) Rydb., and *Agropyron pauciflorum* (Schwein.) Hitchc. (spring habit) which displayed, respectively, ranges of 80, 70, 75, and 70% damage between selections. Selections from the other species were intermediate between these two extremes in the range of differences which were displayed for susceptibility to damage by grasshoppers. Similar differences in susceptibility to grasshopper attacks have been reported for varieties, hybrids, and top-crosses of corn (2).

Ball (1) has reported that many species of grasshoppers are specific in their host requirements and Mail (4) observed that even so-called omnivorous species of the insect show decided food preferences as long as a surplus of green food is available. Brunson and Painter (2) found that even when forced to consume a single species of crop (corn), grasshoppers preferred some plants to others in open-pollinated varieties. These authors concluded that the genetic composition of a plant influenced its susceptibility to attacks by grasshoppers.

It seems probable that the differential feeding of grasshoppers not only on species but also on selections within the species of grasses in the grass nursery at Pullman may be explained by the abundance of green material available and by the food preferences of the grasshoppers. If the inheritance of a selection influences its susceptibility to attacks by grasshoppers, it may be possible to select strains of grasses which will be more highly resistant to grasshoppers than any now produced.

The extreme differences observed between the seedling grasses in resistance to attacks by grasshoppers may indicate a greater ease of establishment of some species of grass than of others in areas where the insects are sufficiently numerous to do considerable damage without completely destroying the plants.

The damage to grasses noted here was done by species of grasshoppers which are generally distributed and which display a considerable host range (5, 6, 7). For this reason it is believed that the relative susceptibility of these grasses to grasshopper damage, as reported, is probably typical of the grasses throughout the crop regions to which they are adapted. If the predominating species of grasshoppers in an area are species which were not observed in the grass nursery at Pullman, it is probable that other results would be observed.

LITERATURE CITED

1. BALL, E. D. Food plants of some Arizona grasshoppers. Jour. Econ. Ent., 29:679–684. 1936.
2. BRUNSON, ARTHUR M., and PAINTER, REGINALD H. Differential feeding of grasshoppers on corn and sorghums. Jour. Amer. Soc. Agron., 30:334–346. 1938.

3. HUME, A. N. An indication of the relative susceptibility of dent and flint corn to injury by grasshoppers. Jour. Amer. Soc. Agron., 23:1071. 1931.
4. MAIL, G. ALLEN. Food preferences of grasshoppers. Jour. Econ. Ent., 24:767-768. 1931.
5. PARKER, J. R., WALTON, W. R., and SHOTWELL, R. L. How to control grasshoppers in cereal and forage crops. U. S. D. A. Farmers' Bul. 1691:1-14. 1932.
6. SHOTWELL, ROBERT L. Species and distribution of grasshoppers responsible for recent outbreaks. Jour. Econ. Ent., 31:602-610. 1938.
7. STRAND, A. L. Montana insect pests for 1935 and 1936. Mont. Agr. Exp. Sta. Bul. 333:1-39. 1937.

DODDER CONTROL IN ANNUAL LESPEDEZAS[1]

R. E. STITT[2]

WITH the introduction of lespedeza into the southern states the field dodder (*Cuscuta pentagona* Engel.)[3] has infested fields of both the annual and perennial lespedezas over widespread areas. This species of dodder was first described by Engelman (3)[4] as occurring near Norfolk, Virginia, in 1842, and has since (7) been found to be prevalent over the eastern half of the United States with lesser infestation ranging to the Pacific Coast and from northern Mexico to Canada. Several European countries (1, 6) have local infestations of field dodder.

The host plants upon which field dodder can grow are numerous, over 100 having been found, this probably being an important factor in adapting the parasite to its present wide habitat and in its persistence. It has been found much more commonly on red clover, alfalfa, and the lespedezas than on other plants.

The following species, some being important cultivated plants and others common weeds, have been observed as hosts of the field dodder. A number of known hosts of minor importance are not included in this list. There may be others of importance as few systematic studies have been made to determine them.

Agropyron repens (L.) Beauv., quackgrass (1)
Amaranthus retroflexus L., pigweed[6]
Beta vulgaris L., beet (1)
Beta vulgaris L. v. *cycla* L., leaf-beet (1)
Brassica oleracea L., cabbage (1)
Cannabis sativa L., hemp (1)
Convolvulus arvensis L., bindweed (1)
Crotalaria sagittalis L.[5]
Cynodon dactylon (L) Pers., bermuda grass (1)
Digitaria sanguinalis (L). Scop., crabgrass[5]
Erigeron canadensis L., horseweed (1)[5]
Hedera helix L., English ivy (1)
Humulus lupulus L., hop (1)
Lespedeza procumbens Michx.[5]
L. sericea (Thunb.) Benth.[6]
L. stipulacea maxim., Korean lespedeza (4)[5]
L. striata (Thunb.) H. & A., common lespedeza (4)[5]
Ligustrum vulgare L., privet (1)
Lolium multiflorum Lam., Italian ryegrass (1)
Medicago sativa L., alfalfa (1)
Nicotiana tabacum L., tobacco (1)
Paspalum distichum L., knotgrass (1)
Perilla nankinensis (Lour.) Decaisne[5]
Plantago lanceolata L., ribgrass (1)
Poa trivialis L., rough bluegrass(1)
Polygonum aviculate L., knotweed (1)[6]
Pueraria thunbergiana (Sieb. & Zucc.) Benth., kudzu[6]
Rhus toxicodendron L., poison ivy[6]
R. typhina L., staghorn sumach[6]
Robinia pseudoacacia L., locust (1)
Rumex acetosella L., sheep sorrel[5]
Salvia coccinea L., sage (1)
Setaria italica (L.) Beauv., foxtail millet (1)
Solanum carolinense L., bull nettle[5]
S. nigrum L., nightshade (1)
S. tuberosum L., potato (1)
Sonchus oleraceus L., sow thistle (1)
Stellaria media L., chickweed[6]
Trifolium incarnatum L., crimson clover (1)
T. pratense L., red clover (1)[6]
T. procumbens L., low hop clover[5]
T. repens L., white clover[6]

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agr. Received for publication January 4, 1939.
[2]Assistant Agronomist.
[3]Many of the manuals give this species under the name *C. arvensis* Beyr. and some list the varieties *typica*, *calycina*, and *verrucosa*.
[4]Figures in parenthesis refer to "Literature Cited", p. 343.
[5]Observed in North Carolina.

The observations given here were made in connection with the development of field dodder on annual lespedezas [*Lespedeza stipulacea Maxim.* and *L. striata* (Thunb.) H & A.] under the climatic conditions existing on the 60° F isotherm in Piedmont, North Carolina. If differences in the life histories of other hosts are taken into consideration these observations should be more or less applicable.

Under field conditions the seedlings have been found from March to September 1, new ones emerging during every period when the soil surface was moist. Germination studies on blotter paper in a moist chamber revealed that germination is delayed over a period of time. The average germination of 12 samples of 100 seeds each was 15% in 16 days, 33% in 40 days, and 53% in 101 days. Variation between the different samples was great, the highest being 79% and the lowest 24%. In experiments carried on in Pennsylvania by Fulton (5) a few seed germinated on the first and second days, with the largest number on the third day and scattered germination thereafter for 66 days. Germination varied from 3 to 40% Seed kept in moist earth was lower in number of viable seed than those stored in dry air. Fulton also found that seed at maturity germinated about as well as when tested 9 months later.

To observe development in the field 20 seedlings which had just emerged were placed at individual locations in Korean lespedeza Only two of these attached themselves to a host, the others dying after a few days. Seedlings under similar conditions out of reach of a host lived from 4 to 9 days while those in a germinator lived from 10 to 15 days after germination.

On Korean lespedeza infestation from a single seedling spread 2 feet in 12 days from time of attachment to the host and a radius of 10 feet was reached before growth was stopped by maturity.

Dodder stems 16 inches in length were taken into the laboratory and left in the shade on a table These stems produced 3 inches of new growth in 10 days The stems died from the opposite end at the rate of 11 inches in 6 days, 14 inches in 11 days and were all dead in 16 days. When placed in the laboratory the plants were a light yellow in color. After 3 or 4 days in the shade a small amount of green coloring matter was observed around the nodes.

Dodder bloomed in 21 days and seed was mature in 38 days from the germination date. Blooming was continuous over a period of 2 to 3 months, varying with the maturity of the host plant. The parts of the dodder plant adjacent to the seed balls die as the seed matures, but the ends of the stems continue to grow as long as the host is alive.

REMOVING DODDER FROM LESPEDEZA SEED

Under Tennessee conditions Essary (4) found that most of the dodder seed can be removed from lespedeza seed by using a lower screen with 16 mesh to the inch and proper adjustment of the air current. A 12-mesh screen was used as the upper screen in cleaning the Korean and common varieties and a 10-mesh screen for the Kobe variety.

Lespedeza seed lots containing considerable amounts of dodder were obtained from the seed-growing area in Piedmont, North Carolina and a number of screen combinations were tried in an attempt to remove the dodder used. The results of these tests are given in Table 1.

TABLE 1 —*Number of dodder seed per pound of sample lespedeza seed before and after cleaning and percentage of lespedeza seed removed as screenings*

Number of dodder seed per pound of uncleaned lespedeza	Diameter of lower screen openings in inches	Number of dodder seed per pound of cleaned lespedeza	Lespedeza seed removed as screenings, %
	Korean Lespedeza		
20,145	1/18	7,830*	8.47
20,145	1/17	5,490	6.09†
20,145	1/16	1,020	13.97
20,145	1/15	765	42.60
20,145	1/14	170	54.89
	Kobe Lespedeza		
13,600	1/18	8,370	—
8,370	1/17	4,590	—
8,370	1/16	3,910	—
	Common Lespedeza		
2,430	1/16	990	

*Seed counts by the Seed Laboratory, Bureau of Plant Industry, U S Dept of Agriculture
†The lower percentage of lespedeza seed removed by the screen with 1/17 inch openings as compared with the 1/18-inch can be accounted for by possible variation in the size of lespedeza seed in the different lots drawn from the bulk sample

The lot of Korean lespedeza seed contained 4.79% dodder, or 20,145 seed per pound of uncleaned lespedeza. Considerable dodder seed passed through a screen with 1/18-inch perforations. As many of the dodder seed were larger than 1/16 inch in diameter it was necessary to use larger screens, but even using 1/14- and 1/15-inch openings which also permitted the passage of lespedeza seed failed to remove all of the dodder. The cleanest sample of lespedeza seed contained 170 dodder seed per pound which would be enough to thoroughly infest a field In getting a sample this clean it was necessary to screen out about 54% of the lespedeza seed, as seed from which the hull has been removed are present in all lots of threshed lespedeza, these being similar in size to dodder. A large amount of the lespedeza seed in the screenings can be recovered, but not all the dodder seed can be removed. Lespedeza screenings containing 16,650 dodder seed per pound when recleaned over a screen with 1/17-inch perforations contained 7,020 dodder seed per pound. Recleaning the seed from this operation over a screen with 1/16-inch perforations lowered the number of dodder seed to 930 per pound and repeating again over the 1/16-inch screen to 170 per pound.

While the cleaning experiments with the common and Kobe varieties were not as extensive as those with Korean, the results obtained gave indications of being no more effective.

As a fanning mill using two screens and an air blast was the only cleaning method used these experiments should not be considered conclusive as other methods may be more adaptable.

METHODS OF CONTROL

Sulfuric acid in a 3% solution by weight has been recommended for field dodder control in lespedeza by Essary (4) in Tennessee and a 5% solution was found effective for dodder by Brown and Streets (2) in Arizona.

In order to study the cost and effectiveness of several methods of dodder control in annual lespedeza different rates of application of several chemicals were made on 125 square foot plats in triplicate.

Solutions of sulfuric acid of 2.5, 3.3, and 5.0% by weight with water, killed both dodder and lespedeza when the plants were thoroughly moistened. Ammonium thiocyanate was found to be effective in amounts of 1 pound or more in 2 gallons of water per square rod, killing both dodder and lespedeza.

"Atlacide", a proprietary mixture usually containing sodium chlorate and calcium chloride, applied at the rate of 1.5 pounds in a gallon of water per square rod killed all plants on the area covered with the spray.

Sodium nitrate, potassium chloride, and ammonium sulfate did not harm either lespedeza or dodder when 6 pounds were applied in 12 gallons of water per square rod

To obtain comparative cost figures on different methods of dodder control, areas of 1/4 acre each having as nearly uniform dodder infestation as it was possible to find were laid out.

The control methods were started in June soon after the grain crop had been removed from the field. At this time the dodder was located in more or less scattered areas varying from 10 to 20% of the plat. Retreatment was necessary at intervals of 9 to 30 days, varying with seasonal moisture conditions During wet weather considerable germination of dodder seeds was observed. It should be emphasized that very thorough inspection is necessary at the time of each treatment which keeps the labor costs high even though the infestation of dodder has been lowered Three methods were found to be of value, each having certain advantages and disadvantages. A comparison of labor and materials used in the experiment are given in Table 2.

The blow torch method in which the plants are wilted proved to be the most satisfactory way to kill dodder. The amount of labor used was no more than that required for other methods. Fuel costs were lower than the usual necessary costs for materials in applying chemicals. Seed balls of the dodder plant are easily destroyed by this method. The lespedeza to which the dodder plants are attached is destroyed, reducing the area considerably in heavy infestations.

Another satisfactory way to control dodder is to cut out by hand the infested parts of the plants and place them in a bag for removal from the field. The labor required is about twice that of destroying with the blowtorch. However, labor is the only item and the economy of the method will depend on the relative prices of labor and materials between the different methods.

Spraying with chemicals requires an outlay for labor similar to that of control with a blow torch. The amount of materials used will vary considerably with the size of growth to which they are applied, raising the costs of late applications.

TABLE 2.—*Labor and materials necessary to destroy 1 acre of dodder infestation in Korean lespedeza*

Date	Man hours	Material	Infestation reduction, %
	Blow Torch		
June 22	9.1	3.6*	15
July 8	8.2	5.4	20
Aug. 3	7.3	5.4	5
Aug. 20	4.8	5.4	5
Totals	29.4	19.8	45‡
	Chemical Spray lbs. "Altacide"		
June 27	8.5	36†	20
July 27	7.3	58	15
Aug. 5	7.3	54	5
Aug. 20	5.4	44	5
Totals	28.5	192	45‡
	Hand Removal		
June 22	15.1	—	10
July 8	16.0	—	15
July 27	13.3	—	10
Aug. 27	14.5	—	5
Totals	58.9		40‡

*Gallons of kerosene.
†Pounds of "altacide."
‡The use of either the blowtorch or chemical sprays killed all plant growth on the infested areas. Total infestation on the area controlled by hand removal may represent some duplication of infested area as the lespedeza recovered from the treatments and allowed reinfestation by germinating seeds.

If the cost of the chemical used is low enough this method may have some place in dodder control. Small amounts of waste sulfuric acid are available at creameries and can be obtained at little expense. This can be used as effectively as commercial sulfuric acid. Precautions must be taken to avoid burns to the operators. None of the chemicals destroyed dodder seed in the amounts applied.

If the infestation of dodder is heavy enough to make the costs of applying these control methods so high as to be prohibitive, some other methods may be followed, such as rotating with a crop on which dodder will not grow. Field dodder does not grow on soybeans or cowpeas so these can be used in rotations in place of the legumes which are readily infested. The various cereals and corn are not attacked.

Seed will live in the soil for five years or longer so that control practices must be followed over a long period of time. Close pasturing has been observed to control dodder on farms. Inspection is necessary in pasturing infested stands to remove any dodder not eaten as growth is often found on unpalatable host plants.

SUMMARY

1. The life history of field dodder on annual lespedeza is given with a list of economic host plants. This species has been found growing on

a number of host plants some of which are listed. Germination under field conditions takes place throughout the growing season. Growth is rapid and blossoms were found 21 days after attachment to the host.

2. Seed of field dodder cannot be entirely removed from annual lespedeza seed by screens.

3. Dodder growing in the field can be destroyed by several methods. The most economical will depend on labor and material costs. The plants can be burned with a blow torch, cut out by hand, or sprayed with chemicals.

4. Effective chemicals were (a) a 2.5% solution by weight of sulfuric acid with water; (b) 1 pound of ammonium thiocyanate in 2 gallons of water, and (c) 1½ pounds of "Atlacide" in 1 gallon of water. These killed all plants of both dodder and lespedeza when thoroughly moistened by spraying.

5. Spraying with chemicals does not prevent dodder seed production if seed balls have started to form.

LITERATURE CITED

1. Bonaventura, G. *Cuscuta pentagona*. Engel., su nuove matrici. Boll. R. Inst. Sup. Agr., Pisa, 8:623–627. 1932.
2. Brown, J. G., and Streets, R. B. Sulphuric acid spray. A practical means for the control of weeds. Ariz. Agr. Exp. Sta. Bul. 128. 1928.
3. Engelmann, George. A monography of the North American Cuscutineae. Amer. Jour. Sci., 43:333–345. 1842.
4. Essary, Samuel H. Control of dodder in lespedeza. Tenn. Agr. Exp. Sta. Circ. 22. 1928.
5. Fulton, H. R. Germination of seed of clover dodder. Penn. Agr. Exp. Sta. Ann. Rpt., 1911–12:250–251. 1912.
6. Hanf, M. Beobachtungen uber das Auftreten von Cuscuta (seide)—arten als gartenschadlinge. Gartenbauwiss, 11:555–568. 1938.
7. Yuncker, T. G. The genus Cuscuta. Mem. Torr. Bot. Club, 18 (2):162–163. 1932.

THE DETERMINATION OF REDOX POTENTIALS OF SOILS[1]

N. J. VOLK[2]

BEFORE beginning a study of the relation of oxidation-reduction (redox) potentials of soils to plant growth and to various chemical and biological processes of the soil, it was deemed advisable to investigate existing methods of determining the redox potentials (Eh) of soils. Preliminary studies soon revealed that none of the existing methods adequately fulfilled the requirements which were believed necessary for the type of investigation contemplated. Methods, to be satisfactory for collecting, preserving, and analyzing samples of soil for redox studies, should (a) inhibit bacterial action so as to prevent reduction within the sample after removing it from the field; (b) prevent oxidation of reduced compounds existing in the soil; (c) refrain from appreciably dissolving substances existing as solid matter in the soil; (d) and result in the redox potential obtained being the same as that existing in the soil in its natural state, or be comparable to it so that one soil can be compared with another.

The investigation reported herein was conducted for the purpose of developing a satisfactory method for determining soil redox potentials.

METHOD OF PRESERVING SAMPLES OF SOIL

Soil-water suspensions containing easily decomposable organic matter will be reduced materially if allowed to stand more than 24 hours at temperatures of 80° to 90° F. Conversely, soil-water suspensions containing easily oxidizable substances will become oxidized appreciably in a few minutes if exposed to atmospheric oxygen, especially if agitated. A number of workers (1, 2, 8, 9, 10, 12)[3] suspended soils in 0.1 N H_2SO_4 and thereby prevented bacterial reduction, but only two, Kohnke (8) and Willis (14), considered the expulsion of air with nitrogen gas a necessary procedure for the prevention of oxidation during analysis. On the other hand, a few investigators disregarded the possibility of oxidation or reduction of the soil during analyses (3, 5, 6, 7, 11, 13).

Since the type of investigation contemplated at this Station involved the collecting of samples from remote locations in the state, thus making it impossible to determine their redox potentials for at least 72 to 96 hours, a method had to be perfected which would prevent oxidation or reduction of samples of soil during transit and storage.

Oxidation of the soils during transit and in storage was inhibited by submerging them in oxygen-free water and corking tightly with paraffined corks.

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[2]Soil Chemist.

[3]Reference by figures in parenthesis is to "Literature Cited", p. 351.

A number of investigators have used 0 1 N H_2SO_4 to add poise to the system and to prevent reduction However, results obtained in this laboratory soon revealed that redox measurements obtained through the use of 0 1 N H_2SO_4 as a preservative were not comparable to those obtained with soil-water suspensions (Table 1) It is believed that the solvent action of 0 1 N H_2SO_4 on the solid phase of the soil brought materials into solution not ordinarily in an active state in the soil

TABLE 1 — *The redox of potentials of samples of soil suspended in water as compared with those suspended in 0 1 N H_2SO_4*

Soil	Eh of soils in millivolts*		Difference in millivolts between the results obtained with the two suspension mediums§
	Suspended in water†	Suspended in 0 1 N H_2SO_4‡	
Wehadkee clay	426	659	233
Holly clay	464	674	210
Leaf fine sandy loam	464	648	184
Hanceville fine sandy loam	468	614	146
Susquehanna sandy loam	476	771	295
Amite clay loam	479	851	372
Houston clay	480	606	126
Oktibbeha clay	480	682	202
Durham fine sandy loam	485	811	326
Davidson clay loam	489	834	345
Norfolk fine sandy loam	490	829	339
Cecil fine sandy loam	494	812	318
Colbert clay loam	500	677	177
Huntington clay loam	501	852	351
Decatur clay	524	840	316
Eutaw clay	532	643	111

*Analyses conducted in atmosphere of nitrogen
†Eh adjusted to pH 6 0 to avoid large adjustment
‡Eh adjusted to pH 3 0 to avoid large adjustment
§These differences should be nearly constant if the methods are to be considered comparable

Since 0 1 N H_2SO_4 could not be used, a number of preservatives, disinfectants, and disinfecting methods were tried in an attempt to find some way in which to inhibit bacterial reduction and yet obtain redox measurements comparable for all soils Mercury compounds, copper compounds, toluene, alcohol, steam, heat, and refrigeration are a few of the things tried All chemical disinfectants tried in sufficient concentration to stop bacterial growth were found to exhibit variable and inconsistent effects on the existing redox of the soil However, cooling the soil-water suspensions to just above the freezing point practically inhibited bacterial action and proved to be a convenient method of preservation Results of several tests with refrigeration are given in Table 2

USE OF NITROGEN GAS TO PREVENT OXIDATION

Apparently very few investigators found it necessary to use nitrogen gas to expel oxygen from suspensions of soil during analyses so as

TABLE 2.—*The prevention of bacterial reduction through the use of refrigeration.*

Soil	Treatment of 1:3 soil-water suspension	Eh in millivolts at pH 6.0, At 35° F, Standing 5 hours	At 35° F, Standing 48 hours	At 85° F, Standing 5 hours	At 85° F, Standing 48 hours	Total millivolts reduction taken place during standing, At 35° F	At 85° F
Congaree	None	551	550	548	493	1	55
Waynesboro		492	489	488	440	3	48
Congaree	1 gram ground filter paper added per 100 cc of suspension	514	511	516	468	3	48
Waynesboro		489	490	489	443	0	46
Congaree	1 gram sucrose added per 100 cc of suspension	516	512	515	424	4	91
Waynesboro		473	478	476	29	0	505
Congaree	1 gram vetch added per 100 cc of suspension	498	498	497	162	0	659
Waynesboro		435	439	434	148	0	582

to prevent oxidation. A great many arable soils tested at this laboratory indicated that as a general rule the amount of oxidation taking place during the analyses was negligible, but on the other hand, soils in a reduced state were found to oxidize considerably during analyses if air was not expelled with nitrogen.

Powdered vetch was added to 1:3 soil-water suspensions in flasks fitted with Bunsen valves. Another set of suspensions was prepared without the addition of vetch. After standing at room temperature for 3 weeks one portion of each of these samples was shaken for 2 hours with 20 cc of nitrogen per 100 cc of suspension and was analyzed for redox potential in an atmosphere of nitrogen gas. A second portion was shaken for 2 hours with 20 cc of air per 100 cc of suspension and then analyzed for redox potential in an atmosphere of nitrogen. The results are given in Table 3.

These results show that for soils in a reduced state it is essential that nitrogen gas be used to keep out the air and thereby prevent oxidation. Since it is difficult to tell if a sample of soil is in a reduced state under field conditions, all analyses for redox measurements conducted at this laboratory were carried out in an atmosphere of nitrogen.

Eh/pH RELATIONSHIP IN SOILS

The theoretical factor of 59 millivolts at 25° C for the relationship of potential to pH holds extremely well where one is dealing with the potential of hydrogen in soils, but in the case of the Eh of soils measured with a blank electrode one is dealing with the potential of

TABLE 3.—*The Eh values of soil suspensions shaken with a definite quantity of air compared with the Eh values when shaken with nitrogen gas*

Total number of soils tested	Treatment of 1:3 soil water suspensions prior to shaking them with air or nitrogen	Quantity of air or nitrogen shaken with 100 cc of soil water suspension for 2 hours	Average Eh in millivolts at pH 6.0*	Increase in Eh value caused by shaking the soil water suspension with air
41	Kept cold (35° F) to prevent bacterial reduction prior to analyses†	20 cc nitrogen 20 cc air	527 531	4
6	Kept at 80° F 3 weeks out of contact with air, thus causing an average reduction of 117 mv	20 cc nitrogen 20 cc air	509 517	8
6	1 gram vetch added per 100 cc suspension and kept at 80° F 3 weeks out of contact with air, thus causing an average reduction of 593 mv	20 cc nitrogen 20 cc air	23 79	56

*Analyses conducted in atmosphere of nitrogen.
†These are arable soils collected at random from the six soil provinces in Alabama. The samples were kept out of contact of the air until the above analyses were made.

innumerable substances in one composite mass. Thus it is the exception rather than the rule that a soil will have an Eh/pH relationship of 59. A study of 132 different types of soil in Alabama showed that the Eh/pH factor, even within close range of the initial pH, varied from 58 to 101 with an average of 66 (Table 4).

TABLE 4.—*The Eh/pH relationship for 132 Alabama soils*

Range of Eh/pH factor in millivolts	Number of samples	Percentage of samples
58 to 60 inclusive	38	28.8
61 to 70 inclusive	74	56.1
71 to 80 inclusive	10	7.6
81 to 90 inclusive	6	4.6
91 to 100 inclusive	3	2.3
101 to above	1	0.7

Peech and Batjer (9) and Bradfield, Batjer, and Oskamp (2) used the factor of 80 for all soils, while Kohnke (8) used the theoretical factor of 59. No great error will be made if one uses a common factor for all soils, providing there is only a small variation in pH between soils. The soils studied at this laboratory varied from pH 4.0 to 8.0, consequently, great errors would be introduced by using a common factor, such as 59 or 80. For example, one particular soil had an Eh of 436 at pH 8.12 and another had an Eh of 667 at pH 4.23. If the common factor of 59 is used and the Eh is adjusted to pH 6.0, the values obtained are 561 and 563, respectively, but when the correct

factors of 59 and 96, respectively, are used the Eh values at pH 6.0 are 561 and 497. Thus, instead of having identical Eh values as shown by using the common factor of 59, these soils actually differed by 64 millivolts which is approximately 13 times the experimental error. Consequently, for all studies on the problem of oxidation and reduction potentials in soils, the Eh/pH factor was determined for each individual soil between pH 6.0 and the pH at which the Eh was determined

CAUSE FOR DRIFT OF POTENTIAL IN POORLY POISED SOILS

Peech and Batjer (9) offered data to show that potential drift (adaptation lag) in poorly poised soils was due to the past history of the electrode; that is, if the electrode had been immersed previously in a solution having a higher or lower potential than the soil to be tested, it would require from a few minutes to several hours for that particular electrode to come into equilibrium with the soil— the time required depending on the poise of that particular soil. However, Burrows and Cordon (4) disagreed with Peech and Batjer and claimed that the drift was caused by the agar bridge and that a liquid KCl bridge must be used to overcome the difficulty The findings at this laboratory support those of Peech and Batjer and the results are given in Table 5.

TABLE 5.—*The cause for potential drift in poorly poised soils immediately following the insertion of the blank electrode into the soil suspension*

Soil studied	Eh of soil in millivolts at pH 4.0		
	Soils in equilibrium with nitrogen	Soils in equilibrium with nitrogen but the agar bridge removed momentarily and treated with a solution of Eh 612 at pH 4.0*	Soils in equilibrium with nitrogen but the blank electrode removed momentarily and treated with a solution of Eh 612 at pH 4.0†
Davidson	586	581	611
Congaree	542	548	610
Decatur	505	511	610
Huntington	522	524	604
Hanceville	546	549	605
Waynesboro	532	534	608
Average of all soils	539	541	608

*The agar bridge was removed from the soil suspension, immersed ½ minute in a buffer at pH 4.0 and Eh 612 It was then simply *rinsed* and replaced in the soil suspension and another Eh reading taken immediately. The blank electrodes were not removed during this operation

†The blank electrodes were treated exactly as the above described treatment for the agar bridges, and then on returning them to the soil suspensions another Eh reading was taken at once

It is interesting to note that treatment of the agar bridge did not affect the Eh value, but that the treatment of the blank electrodes caused an initial reading to be obtained which was almost identical with the buffer in which they had been placed for ½ minute.

After studying a large number of soils it was found that the Eh value became very nearly constant after 2 hours; thus, all determina-

tions of Eh value in water suspensions were made after the blank electrodes had been in contact with the suspension for 2 hours or more Results reported by Burrows and Cordon (4) could not be duplicated in this laboratory.

TYPE OF BLANK ELECTRODES MOST SUITED FOR SOIL SUSPENSIONS

During the early part of the present investigation dealing with oxidation and reduction in soils, platinum foil electrodes about ¾ cm square were used Apparently for no reason at all, electrodes which had been used previously and found to be satisfactory would suddenly be off 25 to 100 millivolts from the other three electrodes in the same suspension (Four electrodes were used simultaneously in each suspension to insure accurate results) After considerable trouble of this nature it was observed on removing the electrodes from the suspension that the faulty one usually had a few little plant roots clinging to it After removing these plant roots and returning the electrode to the original suspension it would usually come to equilibrium with the other electrodes This difficulty with roots was largely overcome through the use of smooth, straight, wire electrodes about 2 cm in length

Electrodes that differed over 5 millivolts from the other three in each set of four were discarded and cleaned before using again The results given in Table 6 indicate the kind of checks one can expect when using properly constructed, properly cleaned, smooth wire platinum electrodes.

TABLE 6 – *A comparison of Eh readings obtained between blank electrodes, 88 electrodes being used and 280 tests being made on 132 different soils.*

Difference in millivolts between two freshly cleaned electrodes immersed in the same soil suspension	Percentage of tests
Perfect agreement between electrodes	40
1 millivolt difference between electrodes	24
2 millivolt difference between electrodes	21
3 millivolt difference between electrodes	7
4 millivolt difference between electrodes	4
5 millivolt difference between electrodes	1
Over 5 millivolt difference between electrodes	3*

*These 3% were discarded and cleaned before being used again

The cause for blank electrodes being over 5 millivolts off was commonly found to be due to minute cracks in the seal which could be detected through the use of a magnifying glass Many times the cracks were so small as to cause an error of only 10 or 15 millivolts, yet the electrode would be off that much consistently. The glass seals should be inspected with a lens at frequent intervals so that electrodes that are cracked will not be discarded for cleaning but will be discarded until reconstructed.

DETAILS OF METHOD FINALLY ADOPTED FOR COLLECTING, STORING, AND ANALYZING SOILS FOR REDOX POTENTIALS

Soils removed from the field were placed immediately in 60-cc bottles containing 30 cc of water saturated with nitrogen gas. Enough soil was added to push the water into the neck of the bottle—this insured about the same size sample of soil at all times and reduced oxidation to a minimum by expelling the air. After the bottles were tightly closed with paraffined corks, they were placed in an insulated box containing dry ice and cooled to about 35° F. All samples were kept at this temperature until they were analyzed for redox potential.

In the laboratory the soil suspensions were transferred to 250-cc flasks, 100 cc of oxygen-free water added, the air displaced with nitrogen, the flasks stoppered, and the suspension shaken vigorously until the soil was dispersed. This operation usually required 1 minute for sandy soils and about 10 minutes for plastic soils. The suspension was allowed to stand for ½ minute and then 50 cc poured into the original 60-cc bottle, the air displaced with nitrogen, and the bottle placed in a mechanical shaker for 2 hours. At the end of this period the sample was again stored in a refrigerator until it could be analyzed. Samples were usually analyzed immediately on being removed from the shaker or within 48 hours after being placed in the refrigerator following dispersion. (Ordinarily, the 10 cc of air remaining in the bottle need not be replaced with nitrogen gas except when soils are highly reduced, Table 3.)

The actual determinations of redox potential and pH were made in an atmosphere of nitrogen[4] by aspirating the suspension with the gas by the use of goosenecked carbon filter funnels of 80-cc capacity. A paraffined cork carrying one tested glass electrode and four blank platinum wire electrodes was inserted into each funnel. Readings were made at the end of 2 hours with an L. and N. 7660 potentiometer. In order to expedite matters where large numbers of samples had to be analyzed, a battery of 30 completely equipped aspirators was kept running simultaneously. All blank electrodes and glass electrodes were constructed in this laboratory.

SUMMARY

The purpose of this investigation was to find a suitable method of preserving samples of soil for redox measurements and to develop an accurate method for determining the oxidation-reduction potentials of soils. The results are summarized as follows:

1. All chemical preservatives tested which effectively inhibited bacterial action in soils also altered the Eh of the soil to such an extent that the results were no longer comparable.

2. Cooling the soils to just above the freezing point was found to be a very effective preservative method.

[4]During a recent conversation with Dr. R. W. Cummings of Cornell University the idea was advanced that sufficient oxygen might be contained in commercial nitrogen to affect the results obtained when determining oxidation-reduction potentials of soils. Several tests were made using different cylinders of nitrogen and highly reduced soils and in all cases the error was less than 5 millivolts per hour when unwashed nitrogen was bubbled through the soil suspensions.

3. Oxidation of reduced compounds in the soil was prevented by the use of water saturated with nitrogen and by performing analytical operations in an atmosphere of nitrogen.

4. The Eh/pH relationship, even within close range of the initial pH, was found to vary from 58 to 101 millivolts for different soils, thus the Eh/pH relationship was determined for each soil studied and correction in Eh made accordingly for differences in pH.

5. Potential drift was found to be due to previous treatment of the blank electrodes and not to the agar bridge.

6. Smooth straight wire platinum electrodes 2 cm in length were found superior to foil since roots clinging to the foil electrode caused misleading results.

7. Details are given for the analytical procedure finally adopted. Results agreeing within 5 millivolts by this method are considered satisfactory.

8. A total of 15 to 20 soils can be analyzed per hour for Eh values by using a battery of 30 aspirators involving 30 glass electrodes and 120 blank electrodes.

LITERATURE CITED

1. BATJER, L. P. Seasonal variation in oxidation-reduction potential of some orchard soils. Amer. Soc. Hort. Sci. Proc., 30:98 101. 1933.
2. BRADFIELD, R., BATJER, L. P., and OSKAMP, J. Soils in relation to fruit growing in New York Part IV. The significance of the oxidation-reduction potentials in evaluating soils for orchard purposes. Cornell Univ. Agr. Exp. Sta. Bul. 592. 1934.
3. BROWN, L. A. Oxidation potentials in soils: Principles and electrometric determination. Soil Science, 37:65 76 1934
4. BURROWS, W., and CORDON, T. C. The influence of the decomposition of organic matter on the oxidation-reduction potential of soils. Soil Science, 42:1 10. 1936.
5. DARNELL, M. C., and EISENMENGER, W. S. Oxidation-reduction potentials of soil suspension in relation to acidity and nitrification. Jour. Agr. Res., 53:73 80. 1936.
6. HEINTZE, S. G. The use of the glass electrode in soil reaction and oxidation-reduction potential measurements. Jour. Agr. Sci., 24:24 41. 1934.
7. HERZNER, R. A. Beitrage zur physikalischen chemie unserer kulturboden. III. Absorptions and redoxpotential. Ztschr. Plansenernahr., Dungung u. Bodenk., 18A:249 264. 1930.
8. KOHNKE, H. E. L. Some factors affecting the oxidation-reduction potentials in soils. Ohio State Univ. Press. 1935.
9. PEECH, M., and BATJER, L. P. A critical study of the methods for measuring oxidation-reduction potentials of soils, with special reference to orchard soils. Cornell Univ. Agr. Exp. Sta. Bul. 625. 1935.
10. ———— - and BOYNTON, D. Soils in relation to fruit growing in New York. Part X. Susceptibility of various New York orchard soils to reduction upon water-logging. Cornell Univ. Agr. Exp. Sta. Bul 667. 1937.
11. SMOLIK, L. Contribution to the variability of redox-potentials of soils. Rocnik X: Sesit 3:272 275. 1935.
12. STEPHENSON, R. E., SCHUSTER, C. E., and SPULNIK, K. J. Oxidation-reduction potentials in orchard soils. Jour. Amer. Soc. Agron., 30:91 96. 1938.
13. STURGIS, M. B. Changes in oxidation-reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. La. Agr. Exp. Sta. Bul. 271. 1936.
14. WILLIS, L. G. Some potential changes induced by liming suspensions of a peat soil. N. C. Agr. Exp. Sta. Bul. 47. 1934.

THE SOIL MOISTURE RELATIONSHIP OF EUROPEAN BINDWEED GROWING IN CORN[1]

A. L. BAKKE[2]

THE European bindweed (*Convolvulus arvensis* L.) with its deeply penetrating root system has a distinct advantage over plants whose roots do not grow so deeply. The competition which must ensue where bindweed is grown in corn is centered directly about the soil moisture and the rainfall. Clements, Weaver, and Hanson (6)[3] state that two plants growing together do not compete as long as the water content and nutrients, temperature, and the light are in excess of the needs of both. When the roots of one enter the area from which the other draws its water supply, or the foliage of the one begins to overshadow the leaves of the other, the reaction of the former modified unfavorably the factors controlling the latter and competition is initiated. The successful plant is able to secure its requirements first.

Corn planted during the early part of May in soil infested with bindweed is able to thrive for a time as the bindweed is rather late in starting in the spring. Later, bindweed is in active competition with the corn for soil moisture, but as long as there is sufficient moisture in the upper soil corn grows satisfactorily, particularly when cultivation is sufficient to keep the bindweed from interferring with the aerial development of the corn plant. As the season progresses, the corn on an infested bindweed area is noticeably smaller than where no bindweed is present. When the corn is picked in the fall the yield in the bindweed areas is usually much less than where the field is free of this weed.

In the 1-square-rod experimental plats at Hawarden, Iowa, in 1932, it was found that plat 74 planted to corn and hoed twice a week throughout the season yielded 27.9 pounds, while from plat 94, also in corn and used as a control, 3.5 pounds were husked. Plat 201, hoed once a week, produced 24.5 pounds of corn in 1932 and 33 pounds in 1933, while the control plat (No. 143) showed a yield in the two years of 10 pounds and 16 pounds, respectively.

Competition such as exists between the corn and the bindweed is largely concerned with the water balance forces. If the roots of bindweed, a perennial, are present in the soil to a considerable depth, they will have the advantage over corn, an annual, as the corn roots are all formed during the current year.

The present investigation represents an attempt to determine the soil moisture relations of the bindweed in well-established areas when grown in association with corn.

METHOD

Two areas, one in a thickly infested area of bindweed in corn and the other free of bindweed, were chosen for the present investigation of the soil moisture

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[2]Research Professor, Botany and Plant Pathology Section.

[3]Figures in parenthesis refer to "Literature Cited", p. 357.

relations. During the years 1933 and 1934, the same areas were used. In 1935, it became necessary to move about 20 rods further north as the first field was seeded to oats. The second field was as nearly as possible comparable to the first. The loess soil was found to have a water-holding capacity of 56.22%. The wilting coefficient was found by direct determination to be 9.07%, according to the Briggs and Shantz (4) method.

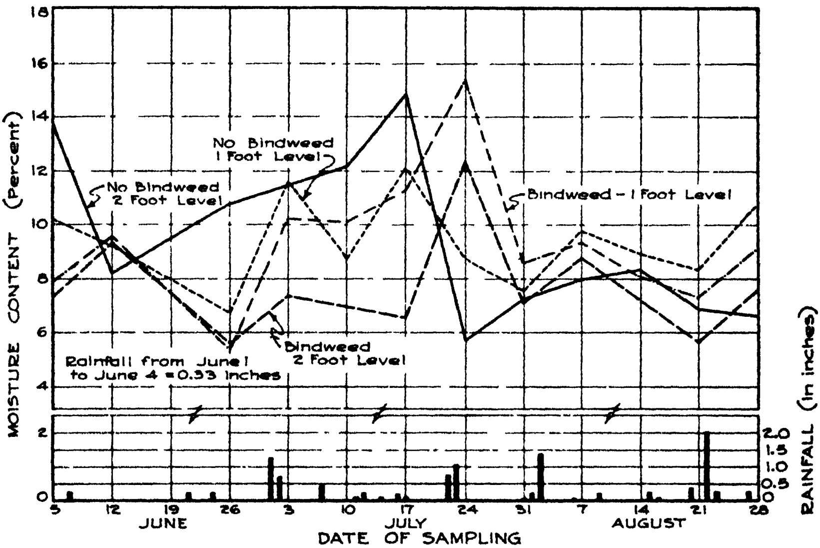

Fig. 1.- Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1- and 2-foot levels. Hawarden, Iowa. 1933.

As the principal feeding roots of both bindweed and corn are in the upper 2 feet of soil, it was decided to obtain the soil samples at weekly intervals during the time of active growth of the two. In 1933 the sampling was begun the early part of June and continued until the latter part of August, but in 1934 and 1935 the samplings were begun in July and continued until the latter part of September. The duplicate soil samples were immediately placed in covered metal soil containers and dried to constant weight in an electric oven at a temperature of 100° C. Rainfall records were kept throughout the season.

1933 RESULTS

From an examination of Fig. 1 it is found that at both the 1- and 2-foot levels the soil moisture was below the wilting coefficient for a greater portion of the time. In the case of the 1-foot level the two curves almost coincided. During the latter part of July the soil moisture of the bindweed-infested area rose considerably above the wilting coefficient. A possible explanation may be attributed to the aerial portion retaining a greater amount of the rainfall than where no bindweed was present. During the month of August there was not much difference in the soil moisture in the two areas.

The soil moisture content at the 2-foot depth showed considerably more moisture in the area free of bindweed during most of June and the early part of July. During August the soil moisture content of the two plats was almost the same

According to Reed (11), June 1933 was the warmest and driest June on record July had a higher temperature average and the precipitation was below average August had a temperature below average and a precipitation which was light. The summer of 1933 was the fourth warmest on record.

From the data submitted during 1933 for the first foot, the rainfall during June and July had little effect on the moisture content. The few light rains from July 10 to July 24 brought about a considerable increase in the moisture content of the bindweed areas. It is possible that the bindweed plants by preventing run-off of the rain produced the increase.

The 1934 graph (Fig. 2) of the moisture relations of the soil in a bindweed area and in one free of bindweed at a depth of 1 foot showed a

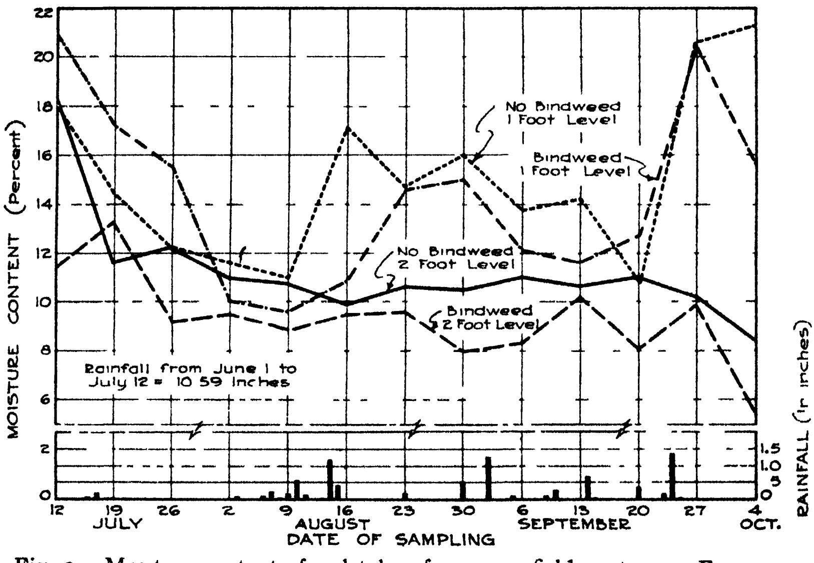

Fig. 2.—Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1- and 2-foot levels Hawarden, Iowa. 1934.

tendency for the latter to have more moisture in the soil than the former. At the 2-foot level the two curves followed each other at about the same variation but both were below the wilting coefficient. There was little increase in the soil moisture content at the 1-foot depth after the rain of August 30 and September 1 even though the aggregate amount was 1.74 inches The high point reached for both areas at the 1-foot level on September 27 was no doubt a result of the heavy rain on September 24 along with lower evaporating environment.

The summer of 1934 (11) was the hottest summer on record. The month of May was the warmest on record. The precipitation during

June and July was a little above normal August was also dry and hot, but the temperature and precipitation were slightly above normal.

On an examination of Fig. 3, it is noticed that the moisture content was above the wilting coefficient for both depths throughout the entire period of 1935. From August 15 until the end of the season there

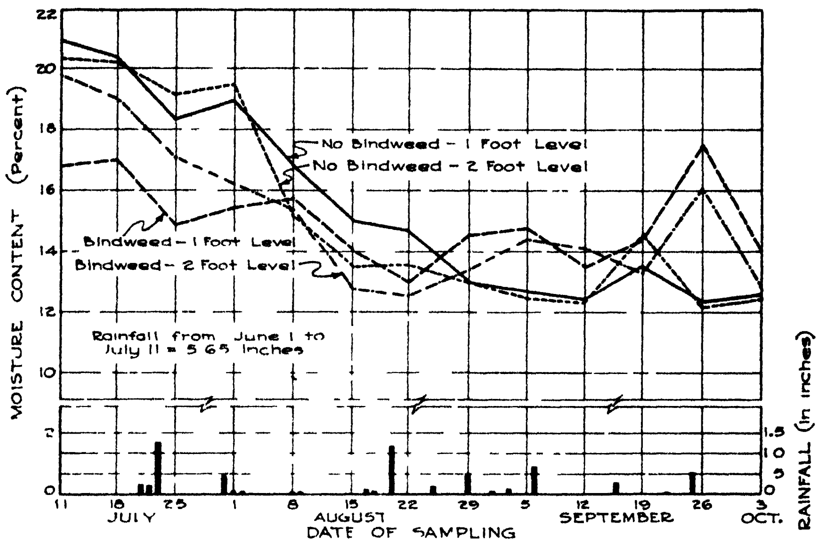

Fig 3 — Moisture content of soil taken from corn field containing European bindweed and free from bindweed at 1 and 2-foot levels Hawarden, Iowa 1935

was very little variation in the soil moisture at the 1- and 2-foot levels The reading on July 11 showed the highest moisture content From the middle of July until the latter part of August, the soil moisture content of the area free of bindweed was generally a little above that of the soil having the bindweed From August 29 until the latter part of September the variations in the soil moistures were rather slight

The month of June 1935 (11) was cool and wet with a total of 5.08 inches of rain. July, August, and September were hot and dry with deficient rainfall

DISCUSSION

From the soil moisture data taken at 1- and 2-foot depths in areas containing the European bindweed and where no bindweed was present, the variation in the soil moisture was rather small. This situation was found to be present whether the soil moisture was above the wilting coefficient or near the wilting coefficient. The bindweed develops a deeply penetrating tap root but at the same time there are a large number of so-called feeding roots in the upper 2 feet of soil. So far, it has not been possible to determine the rate of water movement in the tap root, but no doubt it is of utmost importance in the water balance of the bindweed. The severing of the tap root under water

at a depth of 8 feet, with subsequent cutting of the feeding roots, did not lend itself to a study of the movement of water.

In an examination of the data and the graphs, it is rather significant that throughout much of the time during the years 1933, 1934, and 1935 the soil moisture was near the wilting coefficient. Breazeale (3) finds that a plant may absorb moisture from any soil horizon where water is available, for example a subsoil, and transport this moisture to another horizon where moisture is scarce. The available soil moisture is held by the soil with a force less than the suction force of the plant. The wilting coefficient is assumed to be the state of equilibrium which exists between the suction force of the plant and the adhesive force of the soil. According to Magistad and Breazeale (8) plants growing in soils above the wilting coefficient are able to absorb enough moisture to maintain turgor. As the soil moisture content decreases the rate of water absorption decreases, causing wilting to take place.

At permanent wilting, according to Bakke (1), considerable force is present. Conrad and Veihmeyer (7) have found that if a soil is wet at the beginning of a growing season to the full depth to which roots of the plants normally penetrate, subsequent additions of water by rain can have but little influence on the extent of the root system. Calling attention again to the rather small variation in the soil moisture content at depths of 1 and 2 feet, it would seem that there was additional evidence to support Briggs and Shanta (5) in their contention that all plants reduce the moisture to the same extent up to the attainment of permanent wilting. This relationship was also observed by Veihmeyer and Hendrickson (14) for sunflower plants.

Shantz (12) found that the point of exhaustion of available soil moisture may vary from a little below the wilting point to about one-half the amount under extreme desert conditions. Brezeale (3) maintains further that good crops of deciduous fruits may be produced in an orchard where the soil to a depth of several feet is kept at a little above the wilting percentage during a greater part of the growing season. He has observed that plants can absorb moisture from soils which are only slightly above the wilting coefficient quite as readily as they can from soils at the optimum moisture content Veihmeyer (13) also studied the moisture relation of young prune trees and found that the rate of extraction of moisture by the trees was the same whether the moisture content of the soil is high or low The intensity of the atmospheric evaporating environment seemed to govern the use of water.

The main absorptive roots of agricultural plants, according to Peterhansel (10), is from roots at a depth of approximately 40 cms. The majority of the feeding roots according to Weaver, Jean, and Crist (15) are also in the upper 2 feet of soil surface, even though some of the roots may penetrate to a depth of 8 feet. From the standpoint of being able to extract more moisture from a given soil, there is apparently very little difference between corn and European bindweed.

Pavlychenko and Harrington (9) state that competition of cereals and weeds results in a reduction of the root development of cereals. The competition commences under the soil surface where the root systems compete for water and nutrients.

SUMMARY

Soil samples taken at depths of 1 and 2 feet from corn ground heavily infested with the European bindweed and from ground free of the weed during the summer months of 1933, 1934, and 1935 did not show marked differences in their soil moisture content.

The bindweed was able to maintain itself when the moisture content was below the wilting coefficient. The deeply penetrating root system was in all probability responsible for the action.

Corn does not compete successfully with the European bindweed when the soil moisture content is near the wilting coefficient. A 1-square-rod plat heavily infested with bindweed and planted to corn in 1933 and kept free of bindweed by weekly hoeing produced 33 pounds of corn while the control plat received three cultivations and produced 16 pounds of corn.

LITERATURE CITED

1. BAKKE, A. L. Determination of wilting. Bot. Gaz., 66:81–116. 1918.
2. ———. Experiments on the control of European bindweed (*Convolvulus arvensis* L.). Iowa Agr. Exp. Sta. Res. Bul. In press.
3. BREAZEALE, F. F. Maintenance of moisture equilibrium and nutrition of plants at or below the wilting percentage. Ariz. Agr. Exp. Sta. Tech. Bul. 29:137–177. 1930.
4. BRIGGS, LYMAN J., and SHANTZ, H. L. The wilting coefficient and its indirect determination. Bot. Gaz., 53:20–37. 1912.
5. ———, ———. The relative wilting coefficient for different plants. Bot. Gaz., 53:229–235. 1912.
6. CLEMENTS, FREDERIC E., WEAVER, JOHN E., and HANSON, HERBERT C. Plant competition. Carnegie Inst. Pub. 398. 1929.
7. CONRAD, J. P., and VEIHMEYER, F. J. Root development and soil moisture. Hilgardia, 4:113–134. 1929.
8. MAGISTAD, O. C., and BREAZEALE, J. F. Plant and soil relations at and below wilting percentage. Ariz. Agr. Exp. Sta. Tech. Bul. 25. 1929.
9. PAVLYCHENKO, T. K., and HARRINGTON, J. B. Root development of weeds and crops in competition under dry farming. Sci. Agr., 10:151–160. 1935.
10. PETERHÄNSEL, HEINRICH. Experimentelle Untersuchungen Über die Beziehungen zwischen Bodenfeuchtigkeit und Wassuverbrauch der Pflanzen. Bot. Archiv, 36:99–151. 1934.
11. REED, CHARLES D. Climatological data (Iowa Section in Cooperation with Iowa Weather and Crop Bureau). U. S. D. A. Weather Bur., 43, 1933; 44, 1934; 45, 1935.
12. SHANTZ, H. L. Drought resistance and soil moisture. Ecology, 8:145–157. 1927.
13. VEIHMEYER, Frank J. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia, 2:125–284. 1927.
14. VEIHMEYER, F. J., and HENDRICKSON, A. H. Soil moisture and permanent wilting of plants. Plant Phys., 3:355–357. 1928.
15. WEAVER, J. E., JEAN, FRANK C., and CRIST, J. W. Development and activities of roots of crop plants. Carnegie Inst. Pub. 316. 1922.

NOTES

A METHOD FOR CONTROLLING THE pH OF NUTRIENT SOLUTIONS IN STERILE SAND CULTURES[1]

THE apparatus described in this paper was devised for the purpose of studying the influence of pH on the nitrogen-fixing ability of certain Rhizobia. Difficulties were encountered in obtaining normal root growth, presumably because of lack of balance of the nutrients in the solutions used. The experiment has been discontinued temporarily, but in view of the fact that good pH control was attained under conditions that should make possible continuous sterile irrigation it is thought that a brief description of the apparatus may be of interest to others doing similar work.

A diagram of the apparatus is given in Fig. 1.[2] The nutrient solution was placed in the 40-liter carboy A and the Mariotte flask arrangement was used to maintain a constant head. From this carboy the solution moved through glass and rubber tubing to the 6-inch double-walled irrigator pot B.[3] The soil cavity of the irrigator pot was filled with well-washed white silica sand.[4] The porous cup C embedded in the sand was connected to the reduced pressure line D by means of glass and heavy-walled rubber tubing. A test tube sample trap was inserted in the outflow line at E.

The nutrient solution in the interwall cavity of the irrigator pot was usually at or slightly above atmospheric pressure. A partial vacuum pressure was maintained in the outflow line D and hence also in the porous cup. Under the action of this pressure differential the nutrient solution flowed from the porous inner wall of the pot, through the sand, out through the porous cup C and the brass drainage pipe D to the 40-liter containers F and G. The inclined brass drainage pipe D was 1 inch in diameter and 7 feet long and had spouts for attaching 14 of the pH control units. The nutrient solution for any pot, after passage through the sand, could be sampled for pH determination by clamping off the flow line on either side and substituting an empty test tube for E.

The porous cup was specially made to provide a 1¼ inch space at the sides and bottom for the quartz sand, this arrangement thus permitting approximately radial flow from the pot wall, through the sand, to the inner cup wall. A circular glass plate was placed in the bottom of each pot so as to cut off the moisture supply from the lower surfaces. This was done to keep the flow more nearly radial and to prevent excessive transfer of liquid through the sand at the lower levels

[1]Journal Paper No. J-619 Project 226, Iowa Agricultural Experiment Station, Ames, Iowa.

[2]The irrigator pots and porous cups were obtained from the General Ceramics Company, Refractories Division, New York City.

[3]RICHARDS, L. A., and RUSSELL, M. B. Apparatus for studying water relations in potted plants. Trans. Amer. Geophysical Union, 18th Ann. Meet., 588–592. 1937.

[4]The particle size distribution for the sand seemed to be well suited for the purpose and was as follows: 1.0–0.5 mm, 46.5%; 0.5–0.25 mm, 41.2%; 0.25–0.10 mm, 9.0%; 0.10–0.05 mm, 3.5%.

where the percentage saturation, and hence the moisture conductivity, is somewhat higher.

The vacuum pressure control panel is shown at the upper right in Fig. 1. The aspirator H was connected through the mercury air trap I in series with the bottles J and K to the mercury manometer L. Electric contacts in this manometer operated a solenoid valve in the

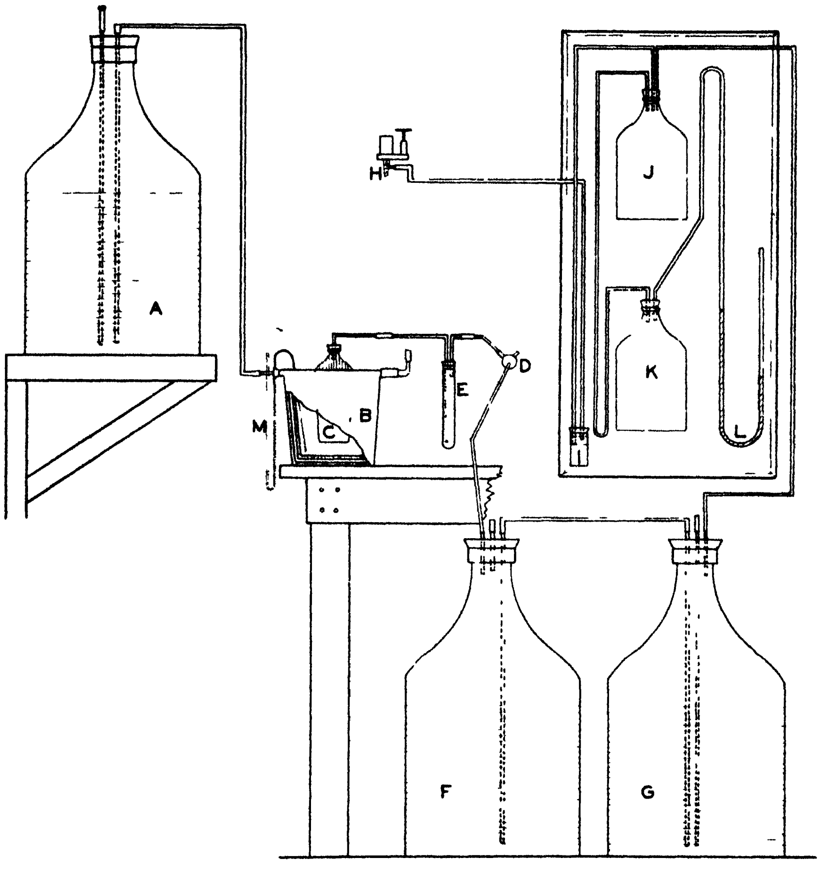

Fig. 1.—Arrangement of porous cells and carboys for controlling the pH of sterile nutrient solution in sand cultures

water line to the aspirator. Resistance to air flow in the line connecting J and K allowed the aspirator to remove slightly more air than was necessary to open the electrical circuit in L, thus preventing continual turning on and off of the aspirator. A constriction near the bottom of the manometer tube effectively prevented oscillation of the mercury level.

Because of the influence of aeration it is desirable to have the percentage saturation of the nutrient solution in the quartz sand the

same in all the pots. As a check on this, glass U-tube manometers of the type shown at M were inserted in each pot. These manometers were filled with water and were plugged with cotton at the sand end. The level of the water in the open arm of a manometer indicates directly the pressure in the nutrient solution at the bottom of the sand column, the cotton plug making it possible to read negative as well as positive pressures During the tests here reported the water table was kept at or slightly below the lower boundary of the quartz sand.

The porous cups at the centers of the pots were all connected to the same vacuum line To balance out variations in the permeabilities of the various pot walls the heights of the supply reservoirs (A) were individually adjusted to bring the water table to the desired level in the sand

It is evident that the liquid content of the quartz sand is determined by the balance between inflow and outflow The effect of temperature on this balance, largely through the change in the viscosity, is shown in Fig. 2. The graph shows thermometer and manometer readings

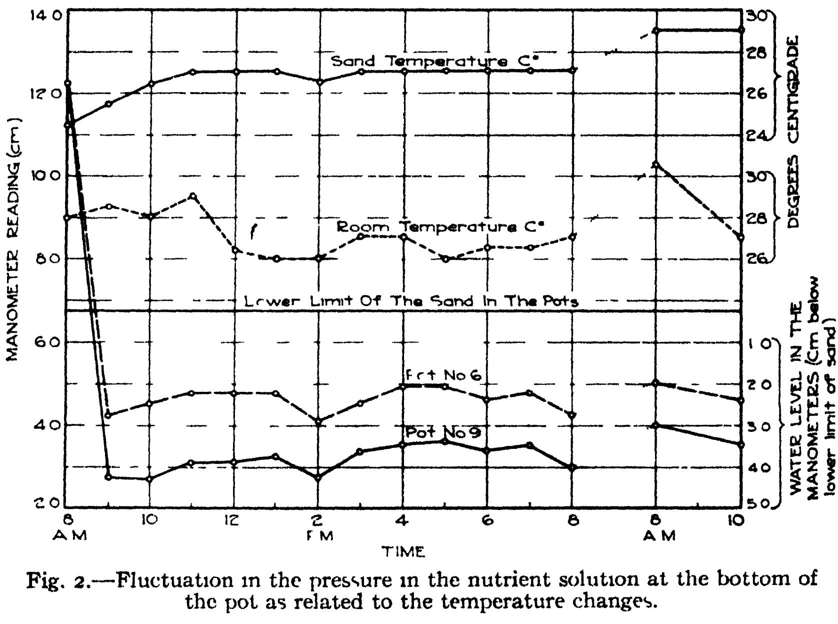

Fig. 2.—Fluctuation in the pressure in the nutrient solution at the bottom of the pot as related to the temperature changes.

plotted against time. As shown by the first two or three points on the graphs, equilibrium flow conditions were quickly established and rather stable.

The first solutions tested in the pots were buffered with tripotassium phosphate (K_3PO_4) and phosphoric acid (H_3PO_4) mixed in varying amounts. Sodium hydroxide (NaOH) was used for adjusting the pH. The phosphate solutions worked well at pH values of 7 or above but could not be used at lower values because of the steep slope of the buffering capacity curve below pH 5.4.

It was desired to have cultures varying in pH from 4 to 7. Based on the work of Tarr and Noble,[5] the next buffering agent tried was potassium acid-phthalate [C_6H_4 (COOH) (COOK)]. The curve in Fig. 3

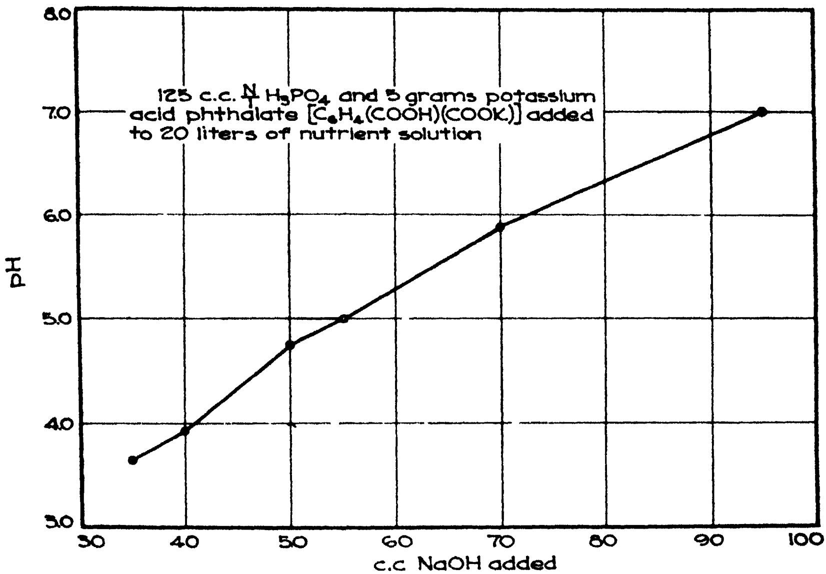

Fig 3 —pH curve obtained by using [C_6H_4(COOH) (COOK)] as a buffer.

shows the relation between the pH and the amount of sodium hydroxide for this buffering agent and Table 1 gives a week's record of the pH of the solution after passage through the sand

TABLE 1 —*The pH values of the original solution, O, before passage through the sand and the spent solution, S, after passage through the sand in which soybeans were growing*

pH desired	Solution	Days 1	2	3	4	5	6	7
4.00	O	4.25	4.25	4.10	4.12	4.06	4.17	4.00
	S	4.30	4.34	4.34	4.31	4.26	4.20	4.07
5.00	O	5.16	5.16	5.14	5.14	5.13	4.95	4.95
	S	5.16	5.19	5.21	5.20	5.18	4.98	5.02
6.00	O	6.06	6.09	6.00	6.11	6.07	6.08	6.06
	S	6.11	6.13	6.12	6.15	6.11	6.08	6.13
7.00	O	7.07	6.95	6.95	7.04	7.02	6.98	7.07
	S	7.02	6.95	6.99	7.02	6.94	7.04	7.01

The precision of pH control, of course, is influenced somewhat by the rate of flow of the liquid through the sand. This rate may be

[5]TARR, L. W., and NOBLE, S. C. The effect of hydrogen-ion concentration upon the growth of seedlings. Del. Agr. Exp. Tech. Bul. 131. 1922.

varied by changing the vacuum pressure in the outflow line. For the data shown the flow rate was about 18 liters per day per pot. A particular advantage for the control system here described lies in the fact that the porous pot wall supplying the solution serves as a bacterial filter thus preventing the contamination of sterile cultures. Tests made in this laboratory by Dr. D. W. Thorne indicate that water from liquid cultures of three common rhizobia and also from a soil infusion was sterile after passage through an irrigator pot wall. Sterile conditions were obtained at the beginning of the experiment by autoclaving each irrigator pot with the sand, central cup, and water level manometer in place.—H. A. WILSON AND L. A RICHARDS, *Iowa State College, Ames, Iowa.*

THE USE OF A TAYLOR PHOSPHATE SLIDE COMPARATOR FOR THE DETERMINATION OF PHOSPHATES IN SOIL EXTRACTS[1]

THE use of rapid chemical tests for determining available plant nutrients in soil has grown extensively during the past few years Several different methods and extracting solutions have been used to remove the so-called available plant nutrients from the soil. Many of these methods employ the use of a porcelain spot plate for determining the amount of phosphorus in the soil extract. Due to the limitations of the spot plate method, a search was made for a more reliable method, rapid enough to fit in with the remainder of the soil testing procedure. The Taylor phosphate slide comparator (Fig. 1) seems to fulfill these requirements. The procedure consumes very little more time than the spot plate method, and the concentration of phosphorus can be determined to within 5 p p m The method is a modification of the Farber and Youngburg[2] procedure for determining phosphates in waters.

REAGENTS

Molybdate solution.—Dissolve 50 grams of sodium molybdate (c.p.) in about 1 liter of distilled water. Filter, add 705 ml of 10 N sulfuric acid, and then dilute to exactly 4 liters.

Concentrated stannous chloride.—Dissolve 16 grams of stannous chloride ($SnCl_2 \cdot 2H_2O$) (c. p.) in sufficient concentrated hydrochloric acid to make 100 ml. of solution. Allow to stand for a few hours for the stannous chloride to dissolve. This solution will keep indefinitely if stoppered tightly.

Dilute stannous chloride.—Dilute 2.5 ml. of the concentrated stannous chloride solution to 100 ml. with distilled water. This solution will not keep and must be freshly prepared every day.

PROCEDURE

Transfer 5 ml. of the soil extract to a 6-inch test tube, add 10 ml. of molybdate solution, 2 5 ml. of dilute stannous chloride, and mix well. A blue color will develop and its intensity will be proportional to the

[1]Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Agronomy.

[2]FARBER, J E., and YOUNGBURG, G E. Determination of phosphates in waters. Indus. & Eng. Chem., Anal. Ed., Jan. 15, 107. 1932.

amount of phosphate present. Maximum color develops rapidly, within a minute. On standing about 10 minutes, slow fading takes place, making it advisable to compare with the color standards within 10 minutes.

To make the reading, three of the five test tubes are placed in the holes back of the slots in the bottom of the base The middle tube is filled with the blue solution resulting from the mixture of soil extract and reagents, while the other two tubes are filled with the soil extract. The slide containing the color standards is then placed in position on the base, and holding the instrument towards a window or other source of daylight (a colorimeter lamp was found to be a convenient

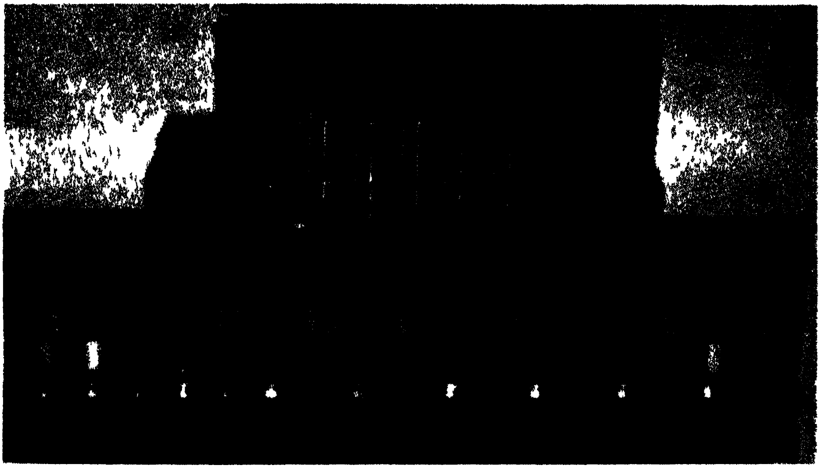

Fig 1 – The Taylor phosphate slide comparator.

and constant source of light), the slide is moved back and forth until one of the color standards is found to match the unknown solution. When a color match is obtained, the concentration in parts per million is read directly from the values on the front of the slide. Since an average acre of soil to a depth of 6 2/3 inches is considered to weigh 2,000,000 pounds the figures on the front of the slide can be multiplied by two and the amount of phosphate expressed as pounds per acre.

The chemicals used in making up the reagents and soil extracting solution should be as free as possible from phosphates and arsenates. If a blank run on the extracting solution contains more than 5 p p.m. of phosphate, it is unsatisfactory. Caution should be exercised in making up and storing the reagents to prevent any contamination.

One of the chief disadvantages of the spot plate method is that frequently the soil extract is somewhat yellow in color. When the molybdenum blue color is developed in this yellow solution, the result is a greenish color which cannot be accurately compared with blue color standards. The Taylor comparator eliminates this source of error by placing a tube of the soil extract back of the color standards.

If the soil extract is colored, it changes the color of the standard so that it coincides very closely with the unknown solution. Another disadvantage of the spot plate method is that it is very difficult to reproduce on paper the exact shades of blue produced by the molybdenum blue reaction. As a result it is difficult to make accurate comparisons with a color chart even though the soil extract is colorless before the reagents are added. The Taylor comparator used liquid color standards and comparisons can be made within 5 p.p.m. with relatively little difficulty.

A modification of Morgan's universal soil testing system was used for the extraction.[3] Ten grams of air-dry soil which have been passed through a 2-mm screen and 20 ml. of Morgan's universal soil extracting solution are placed in a 50-ml. erlenmeyer flask, stoppered tightly, and shaken for 10 minutes. The mixture is then filtered and the filtrate tested for phosphorus and other plant food nutrients.

During the past 3 years the author has made some 6,000 phosphate determinations by this method and the results have been quite satisfactory. Almost all of the soil samples tested have been from soils being used for turf production, such as golf courses, parks, cemeteries, and lawns. About 1,800 of these samples were tested in a research project where more accurate results are necessary than for routine examinations. In both routine and research soil testing the color comparator has given satisfactory results.—T. C. LONGNECKER, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

BOOK REVIEWS

HUMUS: ORIGIN, CHEMICAL COMPOSITION, AND IMPORTANCE IN NATURE

By S. A. Waksman. Baltimore: Williams and Wilkins Co Ed. 2. XIV+526 pages, illus. 1938. $6.50.

THIS edition appears less than three years since the first, and no very extensive changes have been made. Chapter VIII on "Humus Formation in Composts and Manures" has been enlarged by adding additional material on green-manuring and by adding a section on "Composting for Sanitary Purposes." At the end of the book a Chapter XVIII on "Humus and Soil Conservation" (eight pages) has been added.

In addition to these major changes, corrections have been made throughout and references to the most recent work have been inserted. The bibliography has been increased from 1,311 to 1,608 references. The entire book is 32 pages longer than the previous edition. (H.J.C.)

MANUAL OF SEDIMENTARY PETROGRAPHY

By W. C. Krumbein and F. J. Pettijohn. New York: D. Appleton-Century Co., Inc. XIV+549 pages, illus. 1938. $6.50.

THIS volume is a contribution by two members of the Department of Geology of the University of Chicago and is one of the Century Earth Science Series under the editorship of Kirtley F.

[3]MORGAN, M. F. The universal soil testing system. Conn. Agr. Exp. Sta. Bul. 372. 1935.

Mather. In the editor's preface Dr. Mather points out that the petrography of igneous rocks has been studied for well over half a century but that it is only within the past 20 years that any special attention has been paid to similar studies of sedimentary rocks. This new study, however, is not only extremely broad but may have considerable practical importance in such fields as physics, soil science, statistical method, and colloidal chemistry. In fact what has been done in this new field is to be found largely in the journals dealing with these four branches of science. This present volume brings together a complete treatment of the subject for the first time.

It is divided into two parts, the first by Dr Krumbein dealing with sampling, preparation, mechanical, and statistical analyses and, the second by Dr. Pettijohn dealing with shape, mineralogical and chemical analyses, and mass properties.

The book is a highly technical treatment of the whole subject and should appeal to the pure research worker in this and allied fields. It touches the soil scientist at such points as analysis of sediments, including methods of dispersion, separation, size determination, statistical and graphical presentation, as well as identification through optical and other methods Anyone interested in the mineralogical and geological origin of soils from sedimentary sources and in mechanical separation will undoubtedly find the manual very valuable. (R.C.C)

STATISTICAL METHODS FOR RESEARCH WORKERS

By R A. Fisher. Edinburgh Oliver and Boyd Ed 7, XV+396 pages, illus. 1938. 15'

THE preceding editions of this valuable and well-known work by Dr. Fisher have been reviewed in this JOURNAL so comparison with the last edition seems sufficient The text has been increased by 13 pages, 12 of which are found in the additional section, 49 2, entitled "The Discrimination of Groups by Means of Multiple Measurements; Approximate Scores " This important new subject is discussed first by an outline of the development of the best discriminant functions with appropriate tests of significance and, second, by a numerical example and references to the wide variety of problems to which the method is applicable

Section 27, "The Fitting of Curved Regression Lines," has been expanded by using orthogonal comparisons between observations to give a more extended introduction to the theory of orthogonal polynomials and to simplify the arithmetical work. Example 45 under "Technique of Plot Experimentation" has been amplified by the use of covariance in the analysis In Section 30, a paragraph on errors in correlation analysis has been added. A few other changes and additions of minor importance also have been made.

One important change has been the omission of the duplicate, folded tables found at the end of the last edition. The number of sections, tables, and examples found in the 6th edition have not been changed. The press work maintains the high standard found in the other editions. (F. Z. H.)

PRINCIPLES OF GENETICS

By Edmund W. Sinnott and L. C. Dunn. New York: McGraw-Hill Book Co. Ed. 3. XIV+408 pages, illus. 1939. $3.50.

THE general outline and organization of the first edition has not been changed. Literature and problems follow each chapter. The third edition is 33 pages shorter than the second. (1932.)

Most changes affect the more advanced parts of the book which have been completely rewritten. The biometric methods by Charles, in the second edition, are replaced by a simplified treatment of biometrics in connection with multiple factor inheritance (Chapter VI) and the χ^2 method is incorporated in the fourth chapter. The entire evidence gained from salivary chromosome studies is new, and to add to the value of the book as a laboratory guide cultural directions are given in the appendix. A special chapter on inbreeding and heterosis, gene mutations, and chromosome changes will be of extreme value to the practical plant and animal breeder.

With excellent problems attached to each chapter, the present day student may be envied for having such ready access to a field touching on so many human endeavors. (B. R. N.)

HANDBOOK OF FERTILIZERS: THEIR SOURCES, MAKE-UP, EFFECTS AND USE

By A. F. Gustafson. New York: Orange Judd Publishing Co., Inc. Ed. 3. 172 pages, illus. 1939. $1.75.

THE first edition of this little volume was published in 1928; the second in 1931. This new edition is considerably enlarged, both by revision of older material and the addition of new. Like the former editions it is written primarily for the farmer and gardner who want to know more about the functions of the various fertilizer elements, their sources, combinations, crop responses, soil effects, and their purchase and practical use on various kinds of crops. It also includes latest information on home mixing, the use of lime, and crop responses to liming, and ends with a short chapter on organic matter.

For a short, concise, and practical treatment of these various phases of the subject, the book is worthy of a place in the working library of practical growers as well as of amateurs. It should also be found useful by teachers of agriculture. (R. C. C.)

AGRONOMIC AFFAIRS

PROGRAMS OF MEETINGS OF THIRD COMMISSION OF INTERNATIONAL SOCIETY OF SOIL SCIENCE AND OF SUBSECTION I, SECTION VIII, OF THIRD INTERNATIONAL CONGRESS FOR MICROBIOLOGY

THREE symposia dealing with different phases of Soil Microbiology will form the subjects of the meetings of the Third Commission of the International Society of Soil Science and of Subsection I, Section VIII, of the Third International Congress for Microbiology.

The meetings of the Third Commission will be held under the Presidency of Dr. H. G. Thornton of the Rothamsted Experimental Station, England, at New Brunswick, N. J., on August 30–31. These meetings will be followed by a one-day excursion in New Jersey. The meeting of Section VIII, of the Third International Congress for Microbiology, devoted to a discussion of the soil population, will be held on September 4 in New York City, under the Presidency of Prof. Orla-Jensen, President of Section VIII.

The preliminary program of these meetings is as follows:

WEDNESDAY, AUGUST 30, 1–5 P.M.

LEGUMES AND LEGUME BACTERIA

1. A. I. VIRTANEN, Biochemical Institute, Helsinki, Finland—Symbiotic N-fixation by leguminous plants.
2. K. V. THIMANN, Biological Laboratories, Harvard University, Cambridge, Mass., U. S. A.—The physiology of nodule formation.
3. R. NILSSON, G. BJALFVE, and D. BURSTRÖM, Lantbrukshögskolan, Ultuna, Sweden—Growth factors for Rhizobia.
4. W. W. UMBREIT and P. W. WILSON, Dept. of Agr. Bacteriology, Univ. of Wisconsin, Madison, Wis., U. S A.—Studies on the mechanism of symbiotic nitrogen-fixation.
5. F. ALLISON, Bureau of Chemistry & Soils, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Respiration rates of Rhizobium; their estimation and significance.
6. A. DEMOLON, Centre National de Recherches Agronomiques, Versailles, France—Bacteriophage and the growth of legumes (film).
7. H. KATZNELSON, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—Bacteriophage and the legume bacteria.
8. H. G. THORNTON, Rothamsted Experimental Station, Harpenden, England—Strains of nodule bacteria.
9. J. K. WILSON, Cornell University, Ithaca, N. Y., U. S. A.—Symbiotic promiscuity in the Leguminosa.
10. L. T. LEONARD, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Bacteria associated with *Gleditsia triocanthosy.*
11. P. L. GAINEY and J. T. KROULIK, Kansas State Agr. College, Manhattan, Kansas, U. S. A.—The nitrogen fixing efficiency of *Rhizobium meliloti* endogenous to Kansas.
12. W. A. ALBRECHT, Univ. of Missouri, Columbia, Mo., U. S. A.—Some soil factors in nitrogen-fixation by legumes.
13. O. N. ALLEN, Univ. of Hawaii, Honolulu, Hawaii, U. S. A.—Rhizobium—leguminous plant relationships within the cowpea group.
14. A. L. WHITING, The Urbana Laboratories, Urbana, Ill., U. S. A.—Variations in the adaptability of strains of *Rhizobium leguminosarum*.

THURSDAY, AUGUST 31, 9 A.M.–12:30 P.M.

MICROBIOLOGY OF SOIL ORGANIC MATTER

1. CH. BARTHEL and N. BENGTSSON, Lantbrukshogskolan, Ultuna, Sweden—The microbiological decomposition of the organic constituents of barnyard manure.
2. A. G. NORMAN, Iowa State College, Ames, Iowa, U S. A.—
3. D. BURK, Bureau of Chemistry & Soils, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—The nature and extent of decomposition of Azotobacter cell nitrogen.
4. H. MURATA, Kagoshima Imperial College of Agriculture & Forestry, Kagoshima, Japan—Ammonification of dicyanodiamide and its derivatives in soil.
5. C. E. SKINNER, Univ. of Minnesota, Minneapolis, Minn., U. S. A.—Decomposition of amino acids by microorganisms.

6. M. F. MORGAN, Conn. Agr. Exp. Station, New Haven, Conn., U. S. A.—Some considerations in the maintenance of soil organic matter by green manures and cover crops.
7. S. C. VANDECAVEYE, Washington State College, Pullman, Wash., U. S. A.—Microbial activity in organic matter transformation in the soil.
8. F. E. CLARK and CHARLES THOM, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., U. S. A.—Effects of organic matter soil amendments upon the microflora of the rhizosphere of wheat and cotton.
9. S. A. WAKSMAN, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—The proximate method of analysis in the study of organic matter decomposition and of soil humus.
10. J. MARSZEWSKA ZIEMIECKA and J. GOLEMBIOWSKA, The National Institute for Agricultural Research, Pulawy, Poland—Cellulose decomposition in acid soils.
11. G. RUSCHMANN, Institut fur Boden. und Pflanz., Landsberg a.d. Warthe, Germany—The use of new organic fertilizers.
12. D. FEHÉR, Institute of Forestry, Sopron, Hungary—Die Radioaktivität der Wustenboden.
13. H. W. REUSZER, Colorado Agr. Exp. Station, Fort Collins, Colo., U. S. A.—The effect of benzoic acid compounds upon the abundance of microorganisms, including Azotobacter organisms, in a soil.
14. I. KRZEMIENIEWSKI, Institut de Botanique et Biologie, Leopol, Poland—

THURSDAY, 1:30 P.M.–4:00 P.M.

Discussion of Legume program. Prof. E. B. Fred, in charge.
Discussion of Organic Matter program. Dr. Charles Thom, in charge.

THURSDAY, 4:00 P.M.

Conference on Legume Inoculants, Dr. A. W. Hofer, in charge. Anyone interested will please correspond with Dr. Hofer, N. Y. Agr. Exp. Station, Geneva, New York.

FRIDAY, SEPTEMBER 1

Morning.—Visits to Rockefeller Institute, Princeton University and Walker-Gordon Dairy.

Afternoon.—Visits to Nematode Control Laboratory, Cranberry Substation and Salt Marshes.

MONDAY, SEPTEMBER 4, 9 A.M.–1 P.M.

Meeting of Subsection I, Section VIII, of the Third International Congress for Microbiology, Waldorf-Astoria Hotel, New York City.

THE SOIL POPULATION

1. H. J. CONN, N. Y. Agr. Exp. Station, Geneva, N. Y., U. S. A.—The autochtonous flora of the soil.
2. R. L. STARKEY, N. J. Agr. Exp. Station, New Brunswick, N. J., U. S. A.—Influence of plants upon the soil population.
3. A. G. LOCHHEAD, Central Experimental Farm, Ottawa, Canada—The soil population.
4. C. STAPP, Biolog. Reichsanst. f. Land. und Forstwirtschaft, Berlin-Dahlem, Germany—Über Begleitorganismen der Nitrifikations—Bakterien.
5. D. FEHÉR, Kgl. Ung. Palatin Josef Universitat, Sopron, Hungary—Die komplexe Wirkung der Bodentemperatur und der Bodenfeuchtigkeit als regulative Grundfaktoren des Bodenlebens.
6. I. L. BALDWIN, Univ. of Wisconsin, Madison, Wis., U. S. A.—Rhizobia in relation to the general soil population.
7. A. Niethammer, Univ. of Praha, Praha, Czechoslovakia.—Die Pilzflora der Samen und Fruchte unter Hervorhebung ihrer Bedeutung für die Entwicklung der Keimlinge.

8. JAN SMIT, Landbouwhoogeschool, Wageningen, Holland.—The relationship of copper to the development of soil microorganisms.
9. T. GIBSON, Edinburgh and East of Scotland College of Agriculture, Edinburgh, Scotland—The bacterial flora characteristic of soils.
10. P. H. H. GRAY, Macdonald College, Quebec, Canada—
11. K. T WIERINGA, Landbouwhoogeschool, Wageningen, Holland—The ratio of actinomyces to other microorganisms in the soil especially in connection with the appearance of potato scab.
12. VACLAV KAS, Institut agropedologique de l'Etat, Prague, Czechoslovakia—Microbiological characteristics of the climatological soil types.
13. M. WINNIK, Agricultural School, Mikveh-Israel, Palestine—The seasonal changes in bacterial numbers and activities in some Palestinian soils.
14. N. JAMES, University of Manitoba, Winnipeg, Canada—The errors of the plating method.
15. J. E. GREAVES, Utah Agr. College, Logan, Utah Some factors influencing nitrogen fixation.
16. Y. ZIEMIECKA, National Institute for Agricultural Research, Pulawy, Poland The influence of different treatments on the soil population.
17. T. L. MARTIN, Brigham Young Univ., Provo, Utah, U. S. A. - The algal population of the soil.
18. H. A. BARKER, Univ of California, Berkeley, Calif., U. S. A.—The nature and distribution of methane-producing bacteria.

Discussion of program Sir John Russell, in charge.

For reservations, accommodations, and general information pertaining to the meetings of the Third Commission in New Brunswick (August 30 to September 1), communicate with Dr. R. L. Starkey, New Jersey Agricultural Experiment Station, New Brunswick, N. J., in charge of Local Committee on arrangements. For reservations and general information pertaining to the Microbiological Congress in New York (September 2 to 9), communicate with Dr. M. H. Dawson, College of Physicians & Surgeons, 620 West 168th Street New York City, General Secretary of the Congress.

KORSMO'S WEED PLATES

THE third set of Professor E. Korsmo's weed plates, Nos. 59–90, are now available through Koehler & Volckmar A.-G. & Company, Leipzig, Germany. These multicolored plates, representing 138 species of weeds (84×64 cms.), show the important stages in their development. In this last set are such common weeds as *Lepidium draba*, *Agropyrum repens* (L.) P.B. No. 85, and *Circium lanceolatum* (L.) Hill. The quoted price is RM 49.

COMBINED SUMMER MEETINGS OF THE CORN BELT AND NORTHEASTERN SECTIONS OF THE SOCIETY

PRELIMINARY announcement of the combined summer meeting of the Corn Belt and Northeastern Section of the Society to be held in Ohio, June 14, 15, and 16, has been supplied by Dr. L. D. Baver, Department of Agronomy, Ohio State University, Columbus, Ohio, from whom further details may be obtained.

WEDNESDAY, JUNE 14, COLUMBUS

9:00 A.M. Registration at Columbus.

9:30 A.M. Inspection of soils and crops experiments.

12:30 P.M. Box lunch on University Golf Course.
2:00 P.M. Leave golf course for Wooster.
7:30 P.M. Discussion groups at Wooster.
1. Organization of agronomic research in Ohio, and major soil differences and types of farming.
2. Group discussions on research problems in soil fertility, soil biology, soil conservation, forages and pastures, corn, small grains, soybeans, and turfs.
3. Group discussion on the coordination of research and extension in Ohio.

THURSDAY, JUNE 15, WOOSTER

8:30–11:30 A.M. Detailed inspection of certain soils and crops experiments by special interest groups, including forages, pastures, grains, and fertility.
1:00– 5:00 P.M. Inspection of experiments of general interest in addition to those not visited in the morning by a given group.
7:00 P.M. Annual banquet.

FRIDAY, JUNE 16
(All tours and conferences optional)

1. Tour to hydrologic and climatologic projects at Coshocton and New Philadelphia in southeastern Ohio.
2. Tour to Trumbull County Experiment Farm in Northeastern Ohio.
3. Tour to Northwest Experiment Farm (heavy clay land) near Indiana line.
4. Soft wheat breeder's conference at Wooster.
5. Grassland conference at Wooster.

SUMMER MEETING OF SOUTHERN SECTION

THE summer meeting of the Southern Section of the Society will be held in Mississippi August 1, 2, 3, and 4, 1939. Although the details of the program have not been worked out, plans include a study of the cotton breeding and ginning, soil fertility, forage and pasture investigations, and potato starch production. An automobile trip through the state is planned which will take the party to certain of the branch stations and through different soil areas of the state.

MEETING OF WESTERN BRANCH

THE Western Branch of the American Society of Agronomy will meet on the Davis campus of the University of California on June 6 for a tour of crops and soils experiments; and then move to the cooler environs of the Berkeley campus for formal meetings on June 7 and 8. Agronomists outside the region are also invited. Those desiring to present papers or wanting further details should communicate with Mr. Coit A. Suneson, Secretary of the Western Branch, University Farm, Davis, California.

JOURNAL

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American Society of Agronomy

VOL. 31 MAY, 1939 NO. 5

THE GEOGRAPHICAL DISTRIBUTION OF SOIL BLACK PIGMENT[1]

W SHERMAN GILLAM[2]

A STUDY of black pigment in soil necessarily involves, to a minor degree, a study of soil humus These organic fractions are intimately associated with soil genesis, and their importance in characterizing a soil and the significant rôle they play in soil-forming processes, are well recognized. A great number of ideas have been propounded concerning the nature of soil humus but little is definitely known about its true chemical nature

Similarly, very little is known about the geographic distribution of the black pigment, for apparently no investigation has been completed along this line Related work that has been published deals with the distribution of nitrogen or organic matter. These latter two, of course, are very closely associated since they bear a fairly constant ratio to each other However, it does not necessarily follow that organic matter content and pigment content of a soil have any such relationship.

A few authors hold that in red soils, or soils in the subtropical and tropical regions, no dark-colored humus fraction exists, while other investigators maintain that the colored organic fraction is present but its presence is masked by various hydrated oxides.

A study of the chemical nature of soil black pigment was made in this laboratory (4).[3] That fraction of the soil organic matter peptized by 4% ammonia, precipitated by acids, and insoluble in 95% ethanol was designated as the soil black pigment. Various pigment fractions, although isolated from soils in different soil groups, were found to be remarkably consistent in chemical and physical properties, which indicated that the same central nucleus was present in each pigment. For the extraction of these pigments, samples from many soil types were used. This afforded an opportunity for comparing the pigment content of various soil groups, for studying its geographical distribution, and for correlating it with climate.

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Published with the approval of the Director as paper No. 220, Journal Series, Nebraska Agricultural Experiment Station. Received for publication December 5, 1938.

[2]Instructor.

[3]Figures in parenthesis refer to "Literature Cited", p. 387.

The formation of soil pigment and soil organic matter is a function of such factors as climate, vegetation, biological activities, topography, and drainage. Since we do not know which of the above-mentioned factors exerts the greatest influence upon pigment formation, it was necessary to limit the study to those factors for which we have definite values. The other factors we must assume remain constant. Of these five factors probably the most important are climate, vegetation, and biological activities. Our knowledge concerning the microbiological activity in the various soil regions is very meager. The influence of vegetation can be noted in a very general manner, but practically all of the soils studied in this investigation were from a grassland region. On the other hand, we have rather extensive data dealing with the climate of different areas.

The important climatic factors are temperature, precipitation, and evaporation. The latter two are generally combined into a single quotient called the humidity factor. The correlation of black pigment and climate was therefore limited to the influence of temperature, precipitation, and, where possible, to the humidity factor.

THE SOIL SAMPLES

The soils employed in this study were in part taken from the collection of the Agronomy Department of the Nebraska Agricultural Experiment Station and in part were collected for the specific purposes of this investigation. The methods of collection were consistent throughout. All samples were from virgin areas, either meadows or clean roadsides, or in a few cases virgin forests. Generally, they were composites of ten and always three or more cores in a location, these being spaced in a 50 to 100 yard line over a uniform virgin expanse. As a rule, samples were taken with special tubes, but in rare instances a graduated spade was used. Vegetation and surface debris were always removed before sampling, but in preparing the samples for analysis, roots, rhizomes, etc., were never discarded.

Over 300 samples were used in this investigation. Recognizing that in the prairies (8) horizonation of organic matter is not distinctly manifest in the upper foot, all the soils were sampled to an empirical depth, namely, by two 6-inch sections. For this study only the 0 to 6-inch samples were used except in some minor comparisons. The air-dried samples were ground to pass a 1-mm sieve or finer as required for the various determinations of hygroscopic moisture, hygroscopic coefficient, or organic matter and humus extracts.

The location of all samples used are shown in Figs. 1 and 2. Fig. 1 shows the distribution of samples in Nebraska and correlations with rainfall and temperature. Fig. 2, with a few exceptions, shows the geographic distribution of all samples.[4]

[4]All the samples of North Dakota and several of those in South Dakota were collected for the author by Dr. F. A. Hayes of the Bureau of Chemistry and Soils. Other South Dakota samples were collected by J. C. Russel of the Agronomy Department as were also all of the Wyoming and a few of the Kansas samples. A few of the Colorado samples were collected for the author by Dr. L. A. Brown of the Colorado State College. Several additional samples from Michigan, not shown by the map, were furnished through J. O. Veatch of the Michigan State College and Dr. M. D. Weldon of the Nebraska Agronomy Department. Several others from North Carolina were furnished by C. B. Clevenger, North Carolina State College. The Nipe sample from Cuba was furnished by Ray C. Roberts of the Bureau of Chemistry and Soils. All other samples, inclusive of those of Kansas,

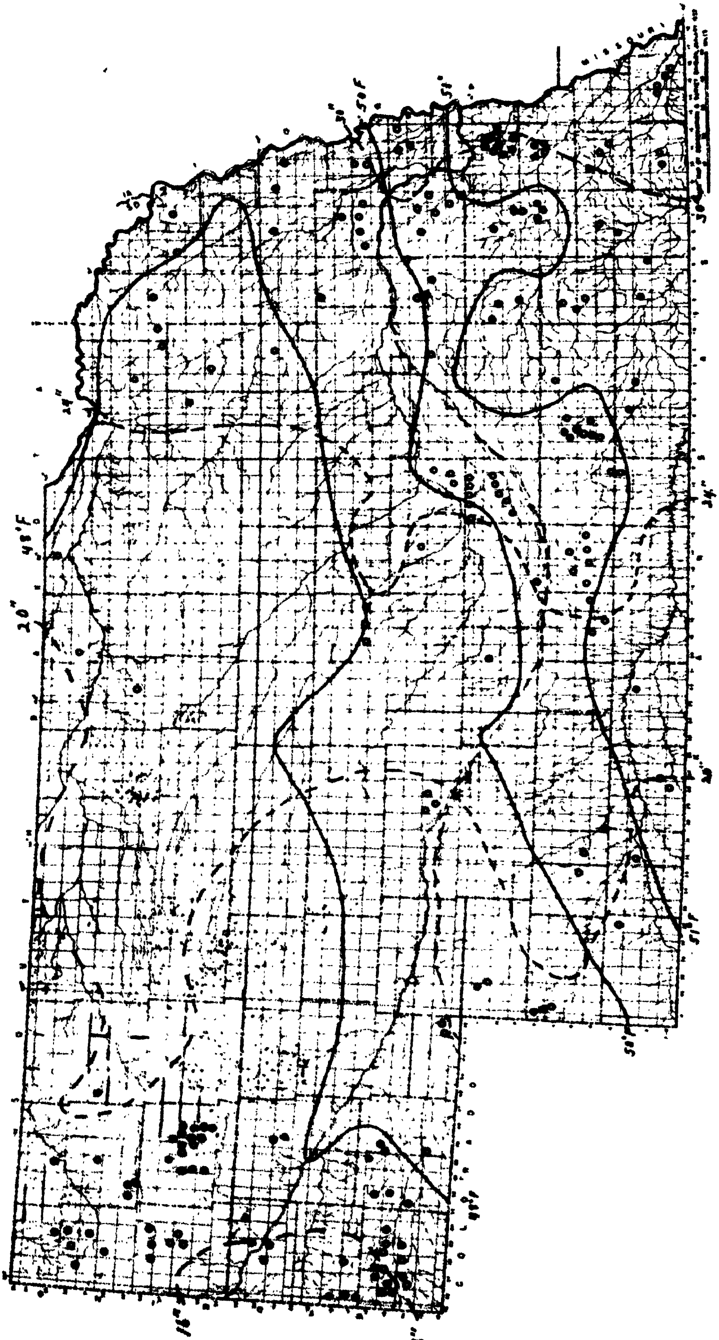

FIG. 1.—Location of all soil samples in Nebraska. Broken lines indicate mean annual precipitation; solid lines mean annual temperature; and each small circle a composite of 10 or more cores.

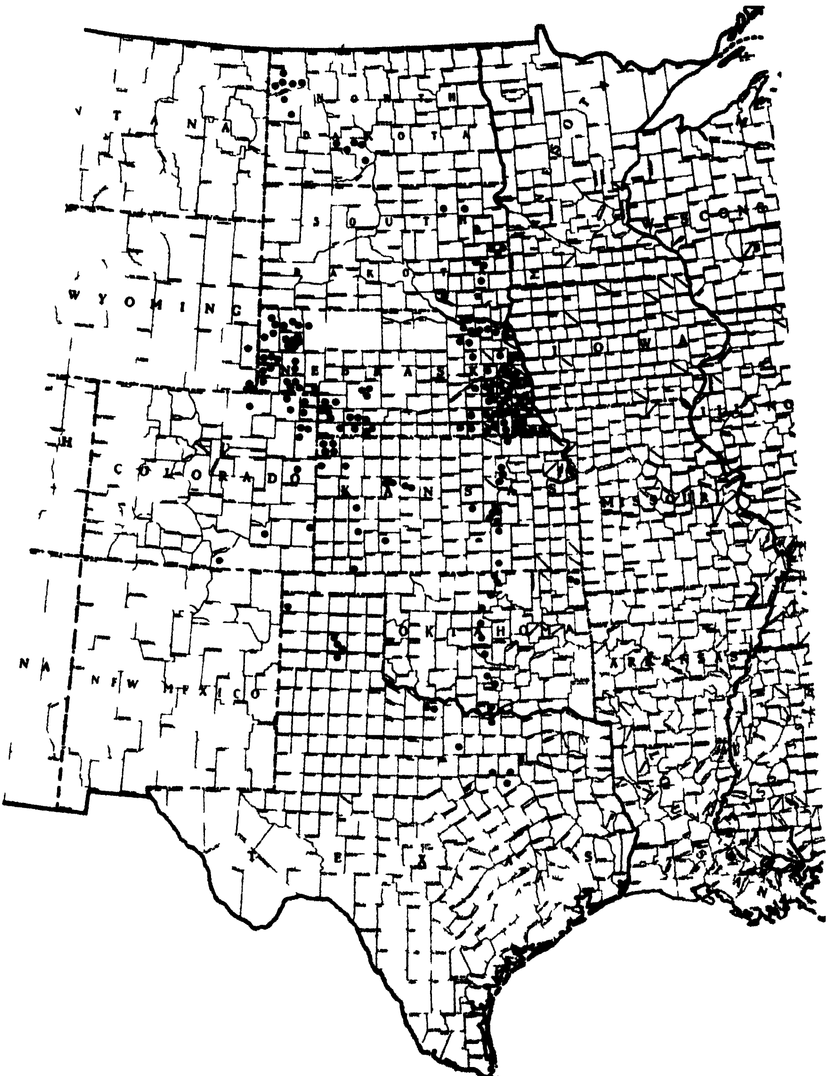

FIG. 2. Distribution of most of the soil samples over the Great Plains area. Each black dot represents a composite of 5 to 10 cores.

DETERMINATION OF PIGMENT CONTENT

The quantitative extraction of soil pigment by means of dilute ammonia or sodium hydroxide is next to impossible. The author, working with samples of muck, has extracted a single sample as many 20 times over a period of two weeks without obtaining any quantitative separation of the pigment.

Oklahoma, Texas, and Colorado, were collected by the author specifically for this subject. Grateful acknowledgment is hereby extended to all those who assisted in the gathering of samples either at the author's request or otherwise.

Thus, an indirect method had to be used for determining the relative amount of soil black pigment present in various soil samples. For this purpose, recourse was had to the colorimetric method, since various workers (1, 2, 3, 11) have concluded that it is sound in principle. However, this method has been subjected to considerable criticism. Probably the most logical explanation for its limitations was pointed out by Gortner (5). In this investigation no attempt was made to calculate the amount of humus present in the soil samples by the colorimetric method. Instead, the relative percentage of humus was determined gravimetrically.

In general, soil organic matter may be considered as consisting principally of two fractions (5); one portion consists of colorless or very slightly colored substances, while the other fraction is highly colored. Therefore, if the ammoniacal extracts of various soil samples were diluted until they contained equal amounts of humus, as determined gravimetrically, and were then compared colorimetrically against some color standard, one could obtain a measure of the relative humus color and the relative pigment content of the different extracts. Thus the relative humus color of the various extracts is simply the ratio of $\frac{\text{standard reading} \times 100}{\text{reading of extract being examined}}$, whereas the relative pigment content was obtained by multiplying the relative humus color by $\frac{\%\ \text{humus in extract being studied}}{\%\ \text{humus in standard}}$. This affords a relative method for studying the distribution of the black pigment.

The colorimeter used was a Campbell-Hurley It consists primarily of two glass cylinders, one of which contains a column of liquid of a definite depth, while the depth of the standard solution in the other cylinder is varied at will by a mechanical method. For illumination, north daylight was used.

PREPARATION OF THE STANDARD SOLUTION

The standard solution used in all colorimetric determinations was obtained from a Barnes silt loam soil of McCook County, South Dakota. This soil had an organic matter content of 5.22% and a humus content of 1.88%. The equivalent of 50 grams of the oven-dry soil was mixed with an equal weight of clean quartz sand and placed in a percolation tube (9). It was then leached with 1% hydrochloric acid until no test for calcium could be obtained in the leachate. Following this, distilled water saturated with carbon dioxide was passed through the soil column until no test for chloride was obtained in the leachate. Finally a solution consisting of 4% ammonia and 2% ammonium carbonate was percolated through the soil and exactly 1,200 cc of the jet black solution collected. Fifty cc of the extract contained 0.0392 gram of ash-free humus, equivalent to 1.88%. Two hundred cc of the extract were then diluted with 4% ammonia to 1,568 cc, thus reducing the humus content to 100 p.p.m., or 1 part of humus to 10,000 parts of solution. This was the standard solution, containing 100 p.p.m. of humus, that was used in the colorimeter. Consequently, the humus content of any extract, in p.p.m. of solution, in p.p.m. of soil, or the grams of humus leached out of the soil sample, could be readily calculated.

METHOD OF EXTRACTION

The procedure used in the preparation of the color standard was likewise used in the extraction of the humus solution from the soil samples. The acid leachate in all cases was pale yellow in color, except for the forest soils where it acquired

a more reddish tint. Each sample was run in duplicate. The ammonia solution was fed to the percolating tube through ground glass tips calibrated to deliver 1.5 cc per minute. Thus, each sample was in contact with the extracting solution for approximately the same length of time.

The relative percentage of humus extracted and its ash content were determined gravimetrically for every sample. Finally an aliquot of each ammoniacal extract was withdrawn, diluted until it contained 100 parts of humus per million of solution, and compared in the colorimeter against the standard. The relative humus color and pigment content were calculated from these readings.

The extracts from several of the samples were collected in 300-cc portions, aliquots withdrawn, diluted, and read in the colorimeter. Parts of humus per million of solution were calculated and plotted against volume of the extract in cc. Five samples chosen at random are shown in Fig. 3.

These curves showing parts per million of humus plotted against volume of extract in a general way fall about as one would surmise. The first 300-cc portions of the ammoniacal extracts from the Kansas samples have a much higher content of humus than do the samples from southern Oklahoma. The northern soils therefore require a slightly larger volume of solution before the extracts become colorless or very faintly colored.

The ammoniacal leachate of practically every sample was very nearly colorless after 600 cc of solution had percolated through the soil column. This is illustrated by the curves in Fig. 3. Consequently, with many samples, only 800 cc of solution were percolated through the tube.

ORGANIC MATTER AND HUMUS DETERMINATION

The organic matter content of all soil samples was determined by the hydrogen peroxide method (7). All samples were run in duplicate and made to check within 0.2%. Most of them checked within 0.1%. Samples having a high content of carbonate were treated with dilute acid to remove the carbonate, and the organic matter was determined on the portion remaining.

To determine the relative humus content, a sample of the ammoniacal extract was evaporated to dryness in a platinum dish, weighed, ignited, and weighed again. From this difference in weight, the relative percentage humus was calculated.

INCUBATIONS

In order to determined whether the relative pigment content, or humus color, could be increased by the addition of organic matter to a soil or sand medium, the following experiment was performed:

The equivalent of 15 grams of oven-dry organic matter and 285 grams of oven-dry Rosebud silt loam soil were placed in each of seven 1-pint milk bottles and thoroughly shaken. Sufficient distilled water was then added to bring the water content up to the moisture equivalent of the soil. The bottles were then capped with cheesecloth, weighed, and placed in a constant temperature room. The weight of each bottle was kept constant by frequent additions of distilled water.

Three organic materials were used in a soil medium, sand medium, and in a sand medium inoculated with water leached through a Marshall surface soil. The following organic materials were used:

Wheat straw	0.42 % N	7.4 % H_2O
Horse manure	1.35 % N	7.5 % H_2O
Alfalfa hay	2.69 % N	7.9 % H_2O

These composts were sampled immediately after mixing and at intervals of 4, 8, 16, 32, 44, and 62 weeks. The percentage of moisture was determined on each sample and the equivalent of 50 grams of oven-dry material was placed in perco-

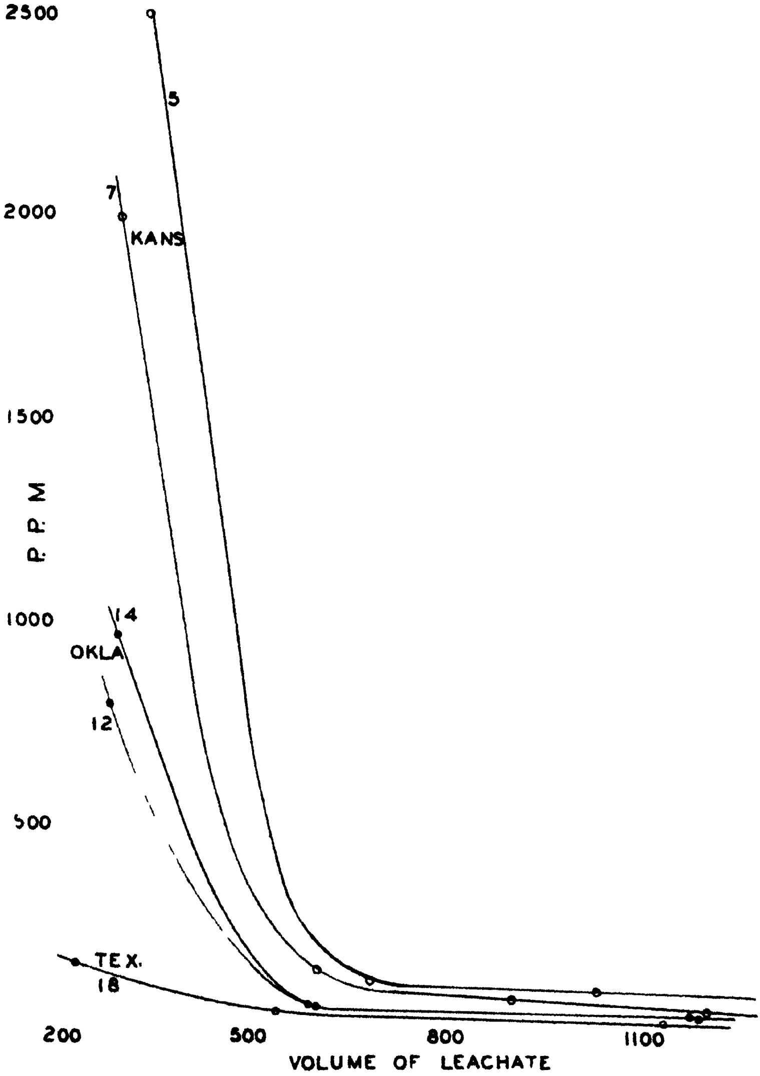

FIG. 3.—Relationship between volume of leachate and humus concentration Curves 5 and 7, 12 and 14, and 18 illustrate this relationship for soils from Kansas, Oklahoma, and Texas, respectively.

lation tubes and leached exactly as the soil samples were leached. The percentage of humus was determined gravimetrically and the extracts compared against the same standard in the colorimeter.

The results showed that addition of organic materials to the soil and sand mediums slightly increased the percentage of ammonia-soluble material of the samples. Alfalfa and horse manure increased this more than the straw. The percentage of ammonia-soluble material, however, did not increase with age and the relative humus color and relative pigment content of the soil likewise were not increased over the 12-month period.

The samples moistened with soil water appeared darker in the colorimeter than those containing only distilled water, but there were insufficient samples to warrant any conclusion being made.

Extracts from the sand medium did not match the color standard, especially in the early part of the incubation period. The solutions were somewhat green or greenish-yellow in comparison to the standard. Toward the end of the period the extracts did become darker colored and matched the standard more closely.

DISCUSSION

In a study involving comparisons of the black pigment in different soils the samples used should possess approximately the same texture. Furthermore, all samples should be from normally developed well-drained soils of the uplands. Consequently, no samples were used from soils developed on a terrace or first bottom. In selecting the soil samples it was not expedient to obtain samples of equivalent texture, therefore the hygroscopic coefficient was used as an expression of texture (10). All samples can then easily be placed on an equivalent basis, and consequently the influence of any factors, which ordinarily would be completely overshadowed by differences in texture, can be illustrated.

Each point in Figs. 4 to 7 and 9 to 10 represents the average of many samples reduced to a uniform textural basis equivalent to a hygroscopic coefficient of 10. All the curves are drawn so that the sum of the squares of the deviations of all points is at a minimum. The data from which these curves were plotted are listed in the appendix of the thesis (4).

PIGMENT TEMPERATURE RELATIONSHIP

In order to study the variation of the soil black pigment with temperature, humidity factors must be kept constant. N.S. quotients were calculated where sufficient data were given for every weather station within the area. The range in N.S. quotients for the entire region was 125 to 260. The area, therefore, is classed as a semi-arid region since the N.S. quotients closely approach the 125–250 range set by Jenny (6). The data plotted in Figs. 4 and 5 were obtained from samples collected, so far as possible, along an isohyet from South Dakota to Texas (Fig. 2). The N.S. quotients along this eastern line range from 140 to 260.

The two curves in Fig. 4 are sigmoidal and illustrate the distribution of soil organic matter and humus with changing temperature. As the temperature increases from around 43° to 55° F both the percentage of organic matter and the humus decrease only slightly. However, from 55° to approximately 61° F the rate of decrease of organic matter and soil humus is at a maximum. The curves represent a spread

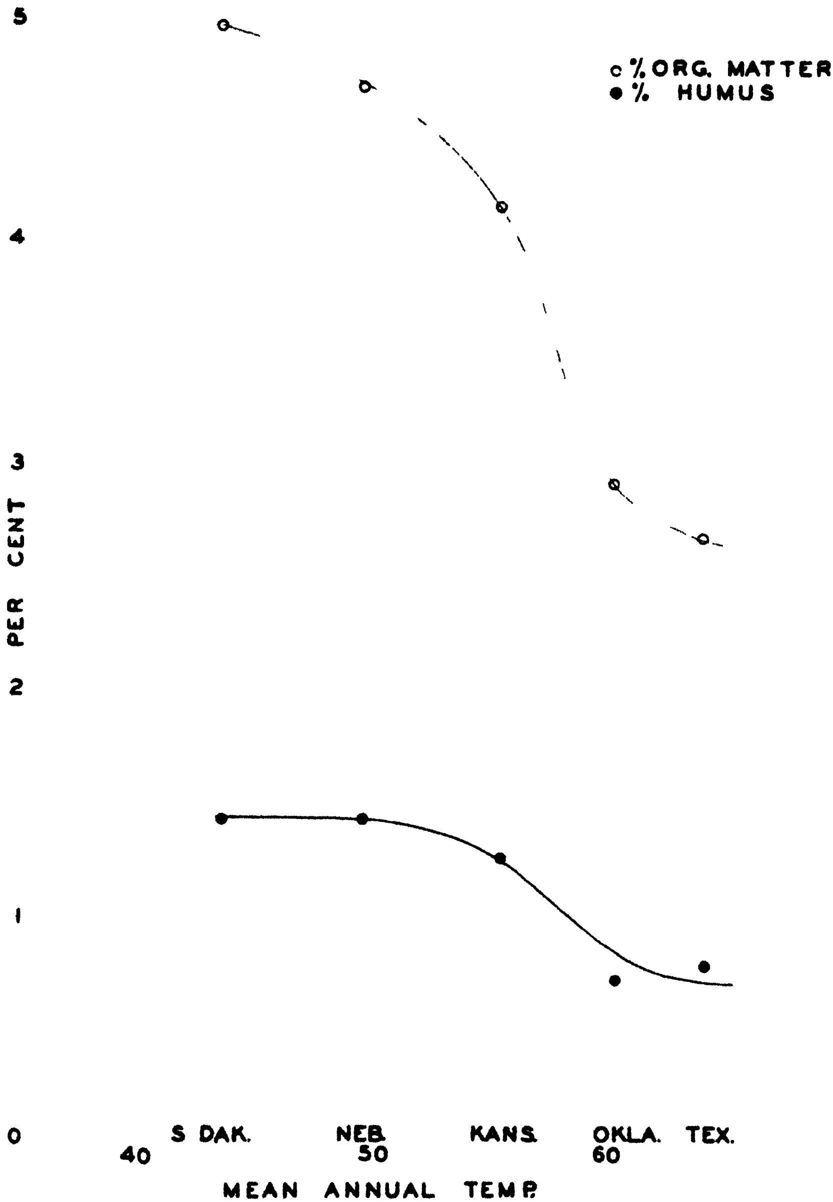

FIG 4.—Relationship between mean annual temperature and the relative humus content and organic matter content where the mean annual precipitation is approximately 29 inches Each point in figures 4 to 7, 9, and 10 represents the average of many samples reduced to a uniform textural basis equivalent to a hygroscopic coefficient of 10.

of approximately 18° F, or 10° C, and illustrate the fact that for a fall of 18° F in mean annual temperature the average soil organic matter and humus content are about doubled.

Fig. 5 brings out the linear relationships of both relative humus color and relative pigment content to temperature. Furthermore, for an 18° F drop in mean annual temperature the relative pigment content of the soil has been increased five or six times, while the relative humus color has increased approximately three times.

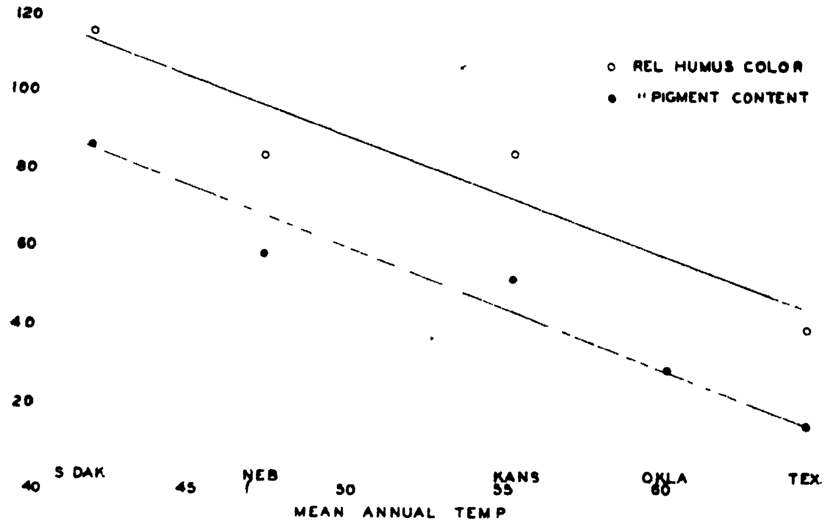

FIG. 5.—Relationship between mean annual temperature and the relative pigment content and relative humus color where the mean annual precipitation is approximately 29 inches

The data plotted in Figs. 6 and 7 were obtained from samples lying on an isohyet line to the west of those plotted in Figs 4 and 5 (Fig. 2) Consequently, we would expect somewhat lower organic matter, humus, and pigment contents than were obtained in the former series of samples. Again we note that the curve for the percentage of organic matter is sigmoidal. The points on the humus curve are possibly too widely scattered to allow any similar conclusions to be drawn.

In this area a drop of 18° F in mean annual temperature has increased the organic matter content only 1.5 times. The curves in Figs. 4 and 6 indicate that the influence of temperature on the organic matter, humus, and pigment contents is slightly greater in the region of higher rainfall than it is in the region of lower rainfall.

Again, in Fig. 7, the parallelism between humus color and pigment content is brought out. Similarly, there is a linear relationship between humus color, pigment content, and mean annual temperature. For an 18° F drop in mean annual temperature the relative pigment content has increased two to two and one-half times and the relative humus color about two to three times. The increase in relative pigment content is much less for this region than for that of the more eastern area.

The correlation between pigment content and rainfall was studied over a relatively small area. The soils investigated lie along an isotherm from eastern Nebraska into eastern Wyoming and Colorado.

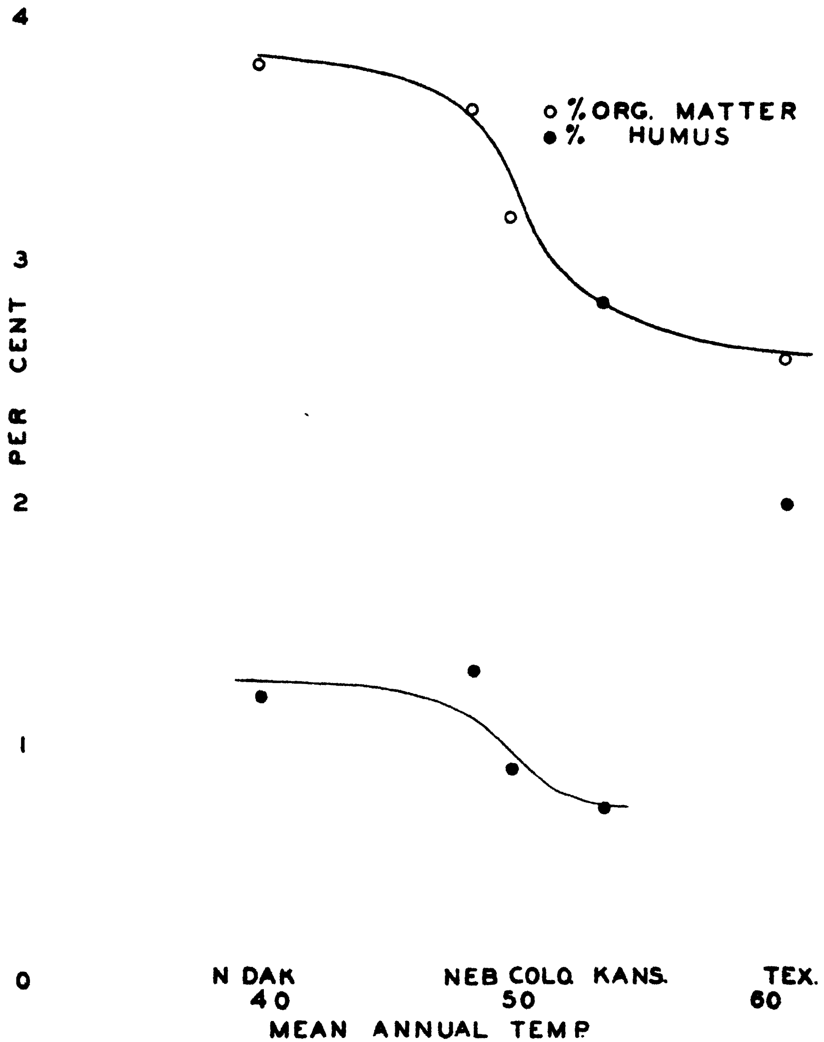

FIG. 6.—Relationship between mean annual temperature and the relative humus content and organic matter content where the mean annual precipitation is approximately 18 inches.

The location of the samples in Nebraska is primarily between the 48° F and 50° F isotherms, continuing on into Colorado and Wyoming (Fig. 1). The samples were divided into three groups as follows: Group 1 consisted of those lying east of the 24″ isohyetal line, group 2 those lying between the 20″ and 24″ lines, and group 3, composed

of samples lying west of the 20" isohyet. In two instances a fourth group was added, consisting of samples in Wyoming and central Colorado.

The results reduced to an equivalent textural basis of H. C = 10, are plotted in Figs. 9 and 10. Groups 1 and 3 are very well represented by soil samples, but group 2 contains a much smaller number. However, this group contains three samples which are composites of five fields each, and the data may therefore be more reliable than is apparent.

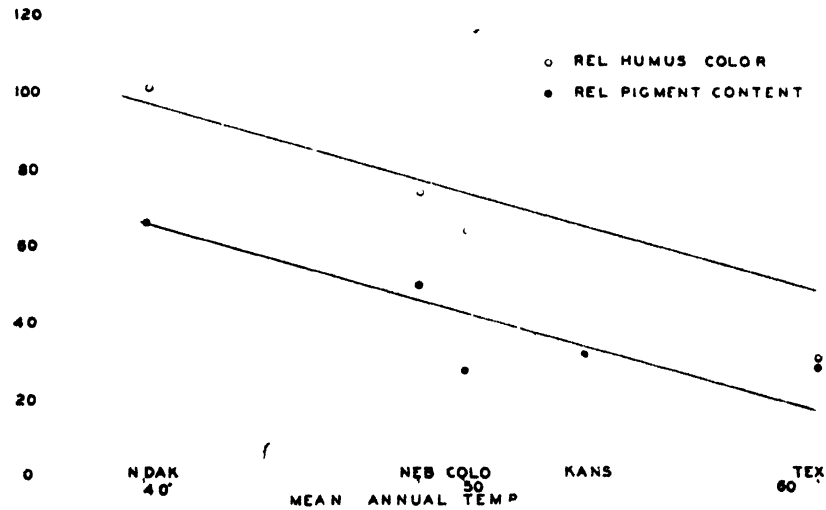

FIG. 7.—Relationship between mean annual temperature and the relative pigment content and relative humus color where the mean annual precipitation is approximately 18 inches

When the organic matter content of soils is plotted against mean annual precipitation one would expect to obtain a simple S-shaped curve (Fig. 8). The curve plotted in Fig. 9 (Colorado through Nebraska) probably lies between the points A and B on the theoretical curve. There are too few soil samples to establish the exact graphical nature of the relationship between organic matter content and rainfall, but apparently it is a curve.

The relationship between humus content and precipitation over this same area is likewise a curve (Fig. 9).

The data from Colorado and Kansas seem to indicate a linear relationship between precipitation and both organic matter content and humus content. However, these samples were few in number and represent a smaller area than the one studied in Colorado and Nebraska. It is more likely that these two lines coincide with a relatively straight-line portion of a curve.

It is quite evident from Fig. 10 that a linear relationship exists between relative humus color and precipitation. On the other hand, the curves for the relative pigment contents are very similar to the

organic matter and humus curves across Nebraska (Fig 9). Even across Kansas this relationship is seen to be a curve.

The humus contents of all soils in Nebraska and closely adjacent areas, when calculated by the colorimetric method, were found to agree rather closely with those obtained by the gravimetric method. However, for more southern or western soils the humus content as calculated colorimetrically was much too low, and conversely the

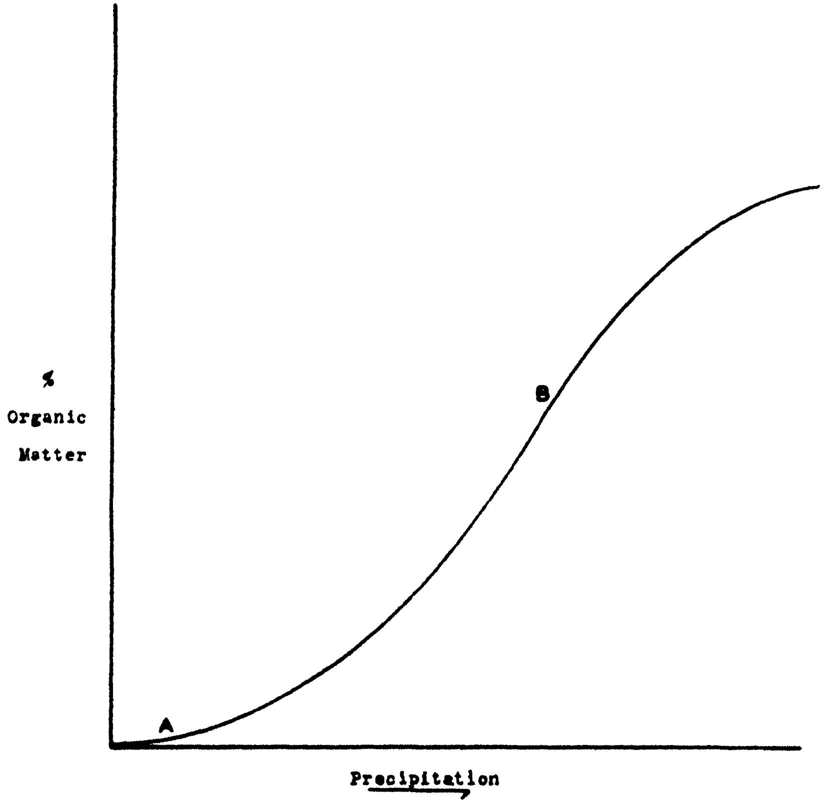

FIG 8—Theoretical curve showing the relationship between mean annual precipitation and soil organic matter content

humus content for more northern soils was too high This discrepancy is due to the differences in relative pigment contents in the soils from the widely separated areas.

Soils from the podsol, laterite, red and yellow, gray-brown forest, prairie, chernozem, chestnut and brown grassland groups have been leached and every one yielded a jet black to very dark brown solution. The extracts from the laterite, podsol, gray-brown forest, and red and yellow groups were a bit too orange to match the standard perfectly. This difference in color is probably significant and may indicate a difference in the constitution of the pigment, or it may merely

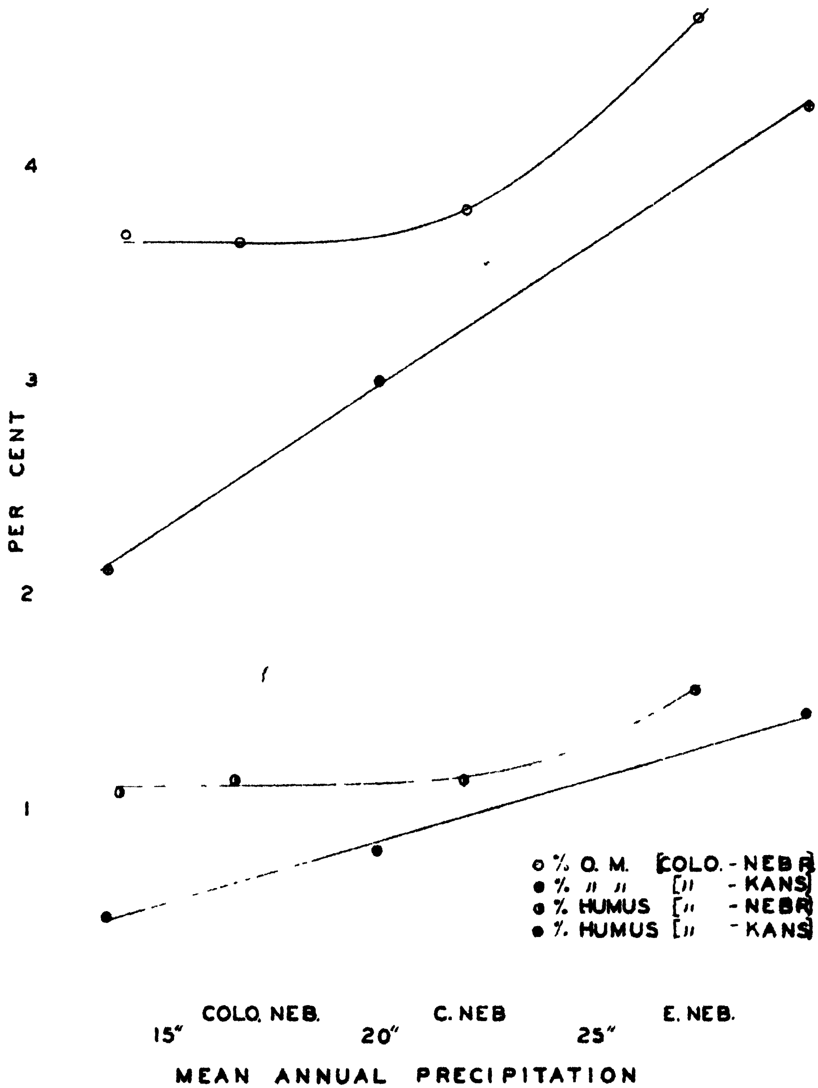

Fig. 9.—Relationship between mean annual precipitation and the relative humus content and organic matter content where the mean annual temperature is 48 to 50° F.

indicate the presence of different indicators or materials in suspension or solution.

With many of the samples studied it was found that, although they might be relatively high in organic matter content, it did not necessarily follow that they were the darkest colored soils or that they contained the most pigment. On the contrary, many soils relatively

low in organic matter content had the highest relative amount of pigment.

COMPARISON OF SOIL GROUPS

From the data assembled in Table 1 a very general comparison of the relative pigment contents, percentage humus, and relative humus color of the soil groups can be made.

TABLE 1. *Comparison of several soil groups with respect to their relative humus and pigment contents.**

Soil group and series	Humus %	Organic matter %	Relative humus color	Relative pigment content	Hygroscopic coeff	% humus HC = 10	Relative pigment content HC = 10
Laterite							
Nipe	2.31		38	46	19.0	1.21	24
Red and Yellow							
Davidson	1.23	4.20	20	13	14.0	0.88	9
Cecil	0.60	1.69	20	6	5.8	1.03	10
Norfolk	0.56	1.86	37	11	2.3	2.43	48
Durham	1.08	4.10	27	16	4.2	2.57	38
Podsol							
Onaway	8.12		48	208			
Gray brown forest soils							
Ontonagon	2.08	5.1	64	71	5.3	3.92	133
—	0.74	2.68	48	19	4.2	1.76	45
Bellefontaine	0.84	2.86	76	34	3.8	2.21	89
Fox	0.76	2.32	60	24	4.5	1.68	53
Newton	0.83	2.32	51	22	2.9	2.86	76
—	1.45		62	48			—
Chernozem							
Barnes	1.77	5.88	137	128	15.0	1.18	86
Barnes	1.79	5.93	121	115	14.4	1.24	80
Barnes	2.55	6.97	138	187	15.5	1.64	121
Barnes	1.88	5.85	109	109	13.5	1.39	80

*Samples taken from top 6 to 8 inches.

Concerning the relative humus content we note that the podsol possesses the greatest amount. Making our comparisons on an equivalent textural basis, we note further that the gray-brown forest soils are second, followed by the red and yellow group, the chernozem group, and finally the laterite. Curiously, the Nipe sample was found to contain practically as much humus as the Barnes soils.

The relative pigment content of these soil groups was found to be highest for the podsol, followed by the chernozem, gray-brown forest, red and yellow, and laterite groups. The high value for the podsol was no doubt due to the presence of a large amount of partially decomposed organic debris from the forest floor. Thus, if we consider the mineral portion of the surface soil, the chernozem group possesses the highest pigment content, followed by gray-brown forest group, and finally the red and yellow and laterite groups. The soil groups fall in the same order when we consider the relative humus color of the extracts. The extracts from the chernozem soils were by far the blackest, as shown by column three. Next in order came the gray-brown

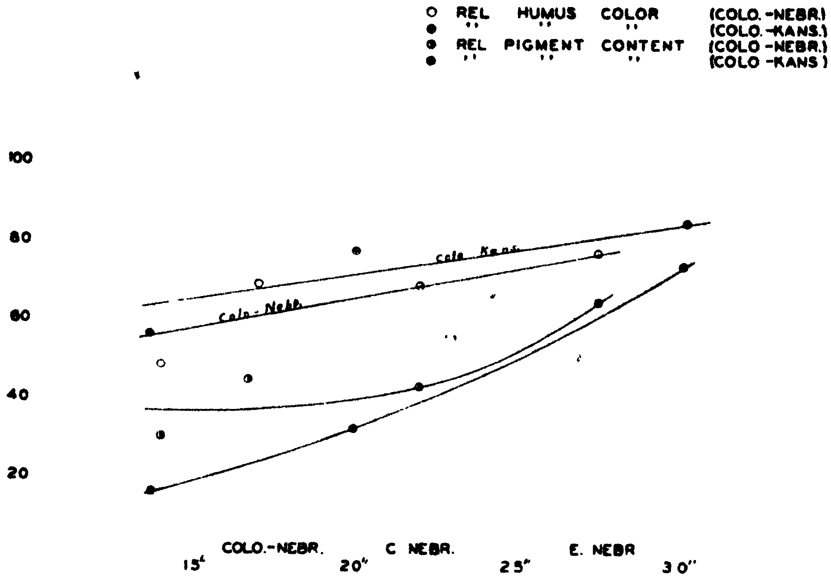

FIG. 10.—Relationship between mean annual precipitation and the relative pigment content and relative humus color where the mean annual temperature is 48° to 50° F.

forest soils, and the podsol. The Nipe extract was as dark as any of the extracts from soils of the red and yellow groups.

CONCLUSIONS

1. Soils having a relatively high organic matter content do not necessarily have the highest pigment content, nor are they always the darkest in color.

2. The second 6 inches of all samples studied were lower than the top 6 inches in relative pigment content.

3. The relative humus color of the soil extract is proportional to the relative pigment content.

4. In regions of approximately equal rainfall, a sigmoid is obtained when organic matter content or relative humus content is plotted against mean annual temperature.

5. Equal differences in precipitation influence the relative pigment, organic matter, and humus contents of the soil more in eastern Nebraska than in western Nebraska.

6. Generally speaking, it can be said that for every fall of 18° F (10° C) in mean annual temperature along the two isohyetal lines studied the average soil organic matter and humus contents are approximately doubled, the relative pigment content of the soil is increased two to six times, and the relative humus color is increased two to three times.

7. Equal differences in mean annual temperature have a greater effect on the relative pigment, organic matter, and humus contents of the soil in the area of greater precipitation.

8. With increasing precipitation along an isothermal line the average soil organic matter, relative humus content, and relative pigment content increase, the graphical nature of these relationships being a curve; but the relative humus color increases linearly.

9. With increasing temperature, along the isohyets, a linear decrease of relative pigment content and relative humus color was noted.

10. The relative pigment content and relative humus color of soil or of sand cultures were not appreciably increased by the addition of organic materials and subsequent decomposition over a period of 62 weeks.

11. Of all soil groups studied the relative humus content was highest in the podsol sample, followed in order by the gray-brown forest soils, the red and yellow soils, the chernozem samples, and finally the laterite.

12. The relative pigment content and humus color, excluding the surface few inches of the podsol, were greatest for the chernozem soils followed by the gray-brown forest soils, the laterite, and red and yellow soils.

13. The laterite and red and yellow samples were fairly high in humus content but low in relative pigment content.

LITERATURE CITED

1. ALWAY, F. J., and PINCKNEY, R. M. The photometric and colorimetric determination of humus. Nebr. Agr. Exp. Sta., 25th Ann. Rpt., 2–16. 1911.
2. CARR, R. H. Is the humus content of a soil a guide to fertility? Soil Science, 3:515–524. 1917.
3. EDEN, T. A note on colorimetric estimation of humic matter in mineral soils. Jour. Agr. Sci., 14:469–472. 1924.
4. GILLAM, W. SHERMAN. The chemical nature and distribution of soil black pigment. Doctor's thesis, Univ. of Nebr. 1938.
5. GORTNER, R. A. The organic matter of the soil: I Some data on humus, humus carbon and humus nitrogen. Soil Science. 2:395–440. 1916.
6. JENNY, HANS. A study on the influence of climate upon the nitrogen and organic matter content of the soil. Agr. Exp. Sta. Bul. 152:15, 18. 1930.
7. JUDD, B. I., and WELDON, M. D. Some changes in the soil during natural succession of vegetation after abandonment in western Nebraska. Jour. Amer. Soc. Agron., 31: No. 3 (1939).
8. RUSSEL, J. C., and ENGLE, E. B. Soil horizons in the central prairies. Amer. Soil Survey Assoc. Bul. 6:1–18. 1925.
9. ————. A method for the continuous automatic extraction of soils. Soil Science, 36:447–450. 1933.
10. ———— and MCRUER, W. G. The relation of organic matter and nitrogen content to series and type in virgin grassland soils. Soil Science 24:448. 1927.
11. STRZEMIENSKA, MARJA. Relation between coloration of alkaline extract of soil and its content of lignin humic complex. Polish Agr. Forest Ann., 32:25–33. 1934.

THE NITROGEN CONTENT OF GRASSES AS INFLUENCED BY KIND, FREQUENCY OF APPLICATION, AND AMOUNT OF NITROGENOUS FERTILIZER[1]

R. I. MUNSELL AND B. A. BROWN[2]

MUCH interest has developed in the problem of maintaining a uniformly high protein content in pasture herbage throughout the grazing season. There are two possible methods of attaining this goal, *viz.*, keeping a high percentage of clover in the sward, and fertilizing the grasses with carriers of nitrogen. It is well known that it is difficult to maintain year after year a large amount of clover in the pastures of the northeastern United States. The experience of the Storrs Agricultural Experiment Station indicates that this is due primarily to the competition of grasses such as Kentucky bluegrass and Rhode Island bent.

A closely related problem is that of maintaining a continuously thrifty lawn free from clover and weeds. Application of certain nitrogenous fertilizers offers the possibility not only of preserving pure stands of lawn grasses but also of helping to maintain a more uniform growth throughout the season.

This paper deals with one phase of a rather broad project which was undertaken to study the effects of various chemicals on the soil, on the botanical composition of the sward, and on the stands of Kentucky bluegrass and Rhode Island bent grasses. The particular phase to be considered here is the effect of the chemical treatments on total nitrogen content of the herbage.

EXPERIMENTAL METHODS

The site of this experiment is a nearly level field of Charlton fine sandy loam soil, a type above the average of Connecticut soils in moisture retentiveness. Since the spring of 1936, 17 different nitrogenous treatments have been applied to triplicate plats, 25 by 6 feet, of pure stands of Kentucky bluegrass and Rhode Island bent which had been seeded in late August of the previous year. Previous to seeding, the pH of the soil was 5.28, and the available phosphorus by the Truog method was 66 pounds per acre. At the time of seeding, 16% superphosphate was applied at the rate of 500 pounds per acre. Carriers of nitrogen only have been added since seeding.

Whenever the tallest herbage of either grass reached a height of 3½ inches, the 64 plats in that particular block were cut with a motor lawnmower equipped with a grass catcher. The clippings were dried and later ground in a Wiley mill for analysis. The nitrogen content of the samples was determined according to the Gunning method for total nitrogen without nitrates (4).[3]

Analyses had previously been run on samples of Kentucky bluegrass under similar fertilization from an adjacent field to determine how much of the total

[1]Contribution from the Department of Agronomy, Storrs (Connecticut) Agricultural Experiment Station, Storrs, Conn. Also presented at the annual meeting of the American Society of Agronomy, Washington, D. C., November 16–18, 1938. Received for publication December 29, 1938.

[2]Research Assistant and Associate Agronomist, respectively.

[3]Reference by number in parenthesis is to "Literature Cited", p. 398.

nitrogen in the grass was in the inorganic forms of nitrate and ammonia. On a dry matter basis, 19 samples analyzed for ammonia varied from 0.001 to 0.016%, or an average of 0.005%. Thirty-nine samples analyzed in 1933 for nitrates varied from 0 to 0.270%, or an average of 0.070%. In 1934, 22 samples contained a minimum of 0 nitrates and a maximum of 0.270%, or an average of 0.040%. In view of the low average nitrate content of Kentucky bluegrass, the procedure for the reduction of nitrates was omitted in the determination of total nitrogen in the present experiment. The data presented in this paper are based on the analyses of samples harvested in 1936 and 1937.

RESULTS AND DISCUSSION

NITROGEN CARRIER

The first factor to be considered is the carrier of nitrogen. All the nitrogen carriers were applied immediately after cutting, except in April, in three applications of 28 pounds actual nitrogen each in April and again in June and August. The analyses of both grasses under eight different fertilizer treatments for each cutting in 1936 and 1937 are given in Tables 1 and 2 and are shown graphically in Fig. 1.

TABLE 1 *Effects of source of nitrogen on percentage of nitrogen in dry matter of Kentucky bluegrass*

Source of nitrogen	1936							
	May 14	June 10	July 1	July 30	Aug 25	Sept 22	Nov 5	Average
None added	2 82	2 36	2 50	2 45	2.45	2 84	2 49	2.56
Sodium nitrate	3 52	2 24	2 30	3 00	2.51	2 55	2 73	2.69
Ammonium sulfate	3 68	2 17	2 21	2 94	2 58	3.47	2 65	2.81
Ammonium carbonate	3 08	2 28	2 32	2 41	2 33	2 94	2 44	2 54
Ammonium chloride	3.68	2 34	2.24	2 80	2 48	3 41	2 59	2.79
Calcium nitrate	3 84	2 29	2.30	2.91	2.58	3.48	2 34	2.82
Cyanamid	3 63	2.17	2.29	2.80	2 62	3 37	2 46	2 76
Urea	3.43	2 17	2.31	2.75	2.56	3 42	2 78	2.77
Calnitro	3 74	2 35	2 50	2.94	2 60	3 12	2.07	2.85
	1937							
	May 18	June 8	June 29	July 19	Aug. 19	Sept 3	Oct. 5	Average
None added	2.34	2.35	2.62	2 76	1 96	2.45	2.81	2.47
Sodium nitrate	2.72	2.30	2.62	3.55	2.21	3.98	3.01	2.91
Ammonium sulfate	2.57	2.20	2.48	3.64	2 38	4 39	2.97	2.95
Ammonium carbonate	2.57	2.30	2.71	3.37	2 19	3.31	2 96	2.77
Ammonium chloride	2.52	2.15	2.60	3.34	2 38	3.92	2.81	2.82
Calcium nitrate	2.78	2 34	2.72	3.33	2.40	4.26	3.00	2.98
Cyanamid	2.54	2.36	2.47	3.59	2.58	3.99	2.77	2.90
Urea	2.59	2.19	2.43	3.41	2.38	4.12	2.94	2.87
Calnitro	2.80	2 32	2.37	3.65	2.44	4 22	2 92	2.96

TABLE 2.—*Effects of source of nitrogen on percentage of nitrogen in dry matter of Rhode Island bent grass.*

Source of nitrogen	1936					
	May 18 19	June 16	July 22	Sept. 14 16	Nov. 3-5	Average
None added	2.85	2.20	2.19	2.32	2.24	2.36
Sodium nitrate	3.36	2.19	2.75	3.06	2.40	2.75
Ammonium sulfate	3.51	2.09	2.66	3.16	2.37	2.76
Ammonium carbonate	2.99	2.15	2.25	2.46	2.17	2.40
Ammonium chloride	3.36	2.18	2.63	3.12	2.35	2.73
Calcium nitrate	3.45	2.18	2.72	3.09	2.38	2.76
Cyanamid	3.29	2.24	2.67	3.10	2.55	2.77
Urea	3.41	2.27	2.51	3.06	2.39	2.73
Calnitro	3.49	2.19	2.63	3.13	2.47	2.78

Source of nitrogen	1937						
	June 1	June 23	July 20	Aug. 28	Sept. 18	Oct. 26	Average
None added	2.45	2.69	3.25	2.92	3.40	2.66	2.90
Sodium nitrate	2.37	2.73	3.29	2.70	3.90	2.62	2.94
Ammonium sulfate	2.33	2.61	3.14	2.60	3.69	2.31	2.78
Ammonium carbonate	2.30	2.49	2.99	2.64	3.52	2.39	2.72
Ammonium chloride	2.39*	2.61	3.04	2.43	3.65	2.23	2.73
Calcium nitrate	2.20	2.65	3.26	2.61	3.74	2.54	2.83
Cyanamid	2.41	2.82	3.22	2.79	3.61	2.66	2.92
Urea	2.46	2.80	3.12	2.77	3.77	2.54	2.91
Calnitro	2.55*	2.83	2.98	2.97	3.70	2.61	2.94

*Estimated.

In general, the application of nitrogen produced a significant increase in the nitrogen content of the herbage. However, a study of the yearly averages for both grasses reveals two exceptions as follows: (a) Due to the inexplicably high nitrogen content of the herbage from the Rhode Island bent check plats in 1937, none of the eight nitrogen carriers produced a significant increase in total nitrogen; and (b) in all cases ammonium carbonate, in contrast to the other seven sources of nitrogen, failed to produce a significant increase over the untreated plats.

It is evident from a study of Fig. 1 that the nitrogen content of both grasses was higher in 1937 than in 1936. The weather data given in Table 3 indicate that this was probably due to more favorable rainfall in 1937. May was the only month in 1937 in which the precipitation was definitely lower than the corresponding month in 1936. The wet August of 1937 made the August applications of nitrogen particularly effective. In general, both years were wetter than the 49-year average. A month by month comparison with the long time average shows that July 1936 and May and July 1937 were the only months during the two growing seasons which were below normal in this respect.

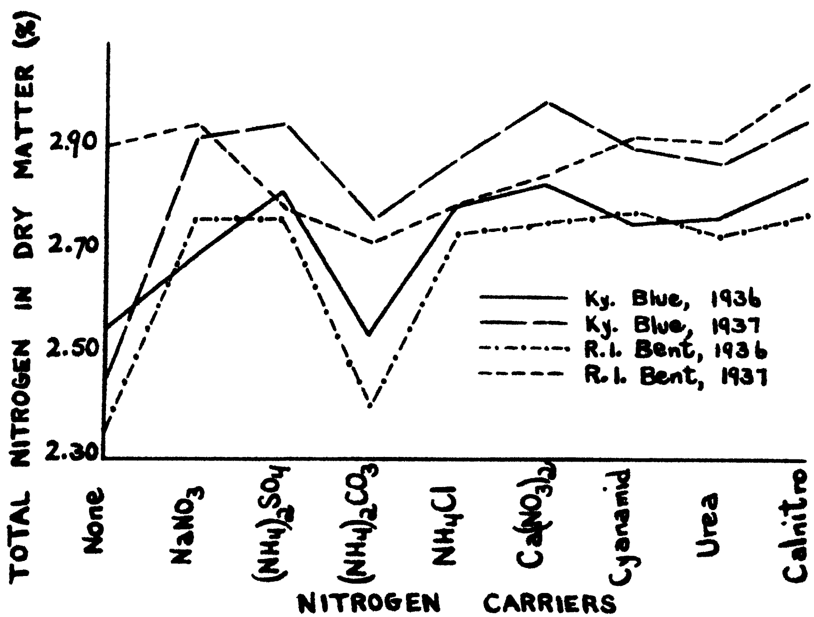

FIG. 1 Effects of source of nitrogen on percentage of nitrogen in the dry matter of Kentucky bluegrass and Rhode Island bent grasses 1936 and 1937

TABLE 3 *Weather at Storrs Conn during growing seasons*

Year	April	May	June	July	Aug	Sept	Oct	Average or total
				Mean Temperature F				
1936	43.10°	59.18	65.64°	69.28°	69.84	62.88	51.71	60°
1937	44.67	58.60	66.85°	71.18	72.42	60.07°	49.70	61°
Average 1888 1937	45.23°	56.42°	64.88°	69.10	67.59	60.89°	50.74°	59°
				Total Precipitation Inches				
1936	3.59	4.33	4.60	2.60	6.23	4.50	5.06	30.91
1937	4.83	3.23	4.67	2.55	9.10	4.46	5.45	34.29
Average, 1888 1937	3.51	3.46	3.11	4.18	4.14	3.84	3.59	25.83

FREQUENCY OF APPLICATION

Another phase of this investigation dealt with the frequency of application of the same amount of nitrogenous fertilizers and the effect on nitrogen content Results of the different treatments are given in Tables 4 and 5 and in the case of Kentucky bluegrass are shown graphically in Figs 2 and 3.

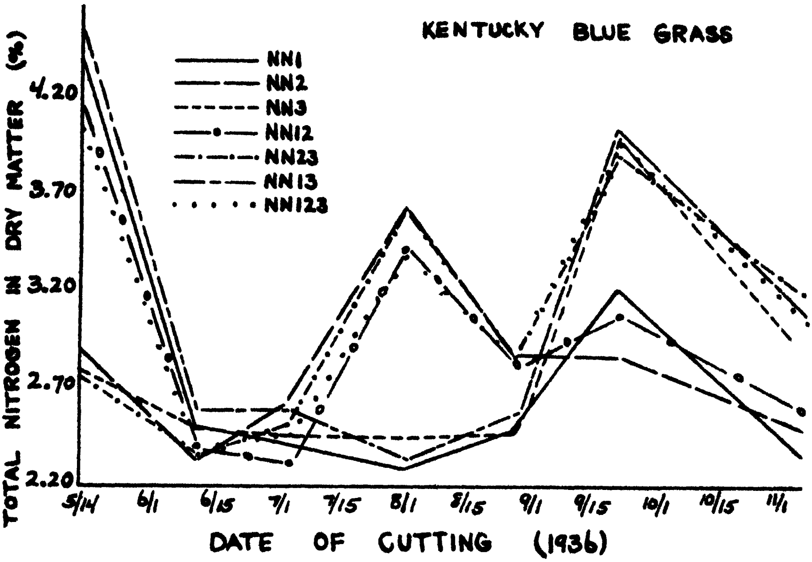

FIG. 2.—Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro, 1936.

TABLE 4.—*Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro.*

Treatments*	1936							
	May 14	June 10	July 1	July 30	Aug. 25	Sept. 22	Nov. 5	Average
NN1	4.38	2.49	2.43	2.27	2.47	3.20	2.38	2.80
NN12	4.15	2.44	2.34	3.44	2.86	3.09	2.62	2.99
NN123	4.09	2.43	2.45	3.43	2.87	3.98	3.08	3.19
NN2	2.87	2.28	2.66	3.67	2.93	2.91	2.52	2.83
NN23	2.76	2.39	2.54	3.67	2.90	3.94	3.21	3.06
NN13	4.54	2.62	2.59	2.30	2.49	4.11	3.10	3.11
NN3	2.79	2.48	2.47	2.45	2.46	4.00	2.97	2.80
None	2.82	2.36	2.50	2.45	2.45	2.84	2.49	2.56
	1937							
	May 18	June 8	June 29	July 19	Aug. 19	Sept. 3	Oct. 5	Average
NN1	3.24	2.60	2.68	3.04	2.46	2.73	2.51	2.75
NN12	3.14	2.51	2.82	4.25	2.83	3.40	2.82	3.11
NN123	3.07	2.60	2.90	4.30	2.97	4.77	3.30	3.41
NN2	2.53	2.34	2.71	4.11	2.35	3.00	2.80	2.83
NN23	2.43	2.36	2.74	3.93	2.60	4.60	3.28	3.13
NN13	3.01	2.62	2.70	3.12	2.42	4.58	3.31	3.11
NN3	2.54	2.58	2.96	2.93	1.98	4.24	3.23	2.92
None	2.34	2.35	2.62	2.76	1.96	2.45	2.81	2.47

*All nitrogen from calnitro. NN = 56 pounds elemental nitrogen. 1 = applied in April; 2 = applied in June; and 3 = applied in August.

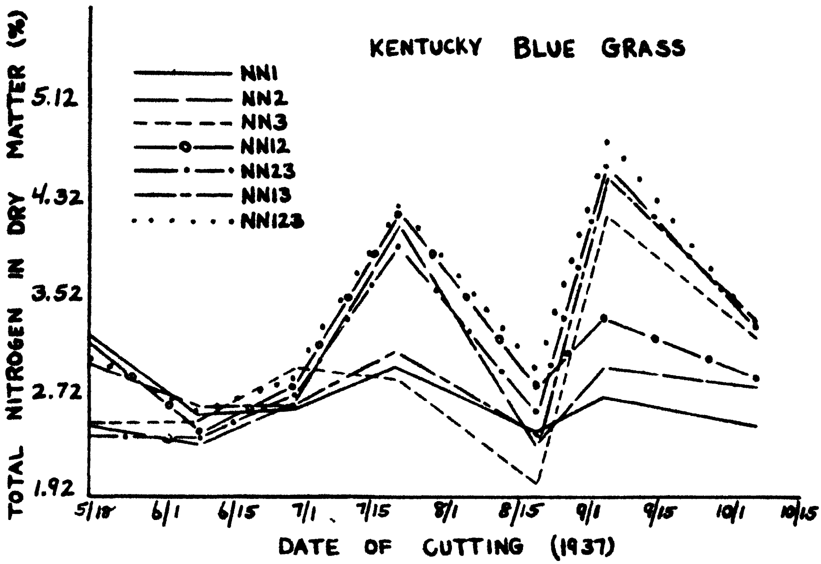

FIG. 3 – Percentage of nitrogen in the dry matter of Kentucky bluegrass as affected by the frequency of application of calnitro, 1937

TABLE 5 – *Percentage of nitrogen in the dry matter of Rhode Island bent grass as affected by the frequency of application of calnitro*

Treatments*	1936						
	May 18 19	June 16	July 22	Sept 14 16	Nov 3 5	Average	
NN1	3.64	2.46	2.35	2.37	2.30	2.62	
NN12	3.85	2.31	2.97	2.30	2.22	2.73	
NN123	3.83	2.43	2.98	3.52	2.63	3.08	
NN2	2.92	2.17	2.82	2.26	2.16	2.47	
NN23	2.82	2.19	2.77	3.49	2.60	2.77	
NN13	3.97	2.34	2.13	3.75	2.71	2.98	
NN3	3.09	2.16	2.04	3.84	2.58	2.74	
None	2.85	2.20	2.19	2.32	2.24	2.36	
	1937						
	June 1	June 23	July 20	Aug. 28	Sept 18	Oct 26	Average
NN1	2.79	3.04	2.93	2.96	3.12	2.54	2.89
NN12	2.72	3.09	3.46	3.10	3.19	2.48	3.01
NN123	2.65	3.03	3.55	3.18	4.39	3.36	3.36
NN2	2.37	2.62	3.56	3.07	3.29	2.44	2.89
NN23	2.38	2.57	3.64	3.13	4.53	2.98	3.21
NN13	2.80	2.95	2.98	2.91	4.41	2.96	3.17
NN3	2.42	2.81	3.10	3.04	4.35	3.00	3.12
None	2.45	2.69	3.25	2.92	3.40	2.66	2.90

*See footnote to Table 4

Calnitro was the only source of nitrogen on this section and was added at a rate to furnsih nitrogen at 56 pounds per application.

In both years, Kentucky bluegrass from plats receiving nitrogen in April only had its highest nitrogen content in the first cutting in May. There was a rapid drop in June and no further marked increase during the season.

A study of Figs. 2 and 3 reveals that the response to April nitrogen of Kentucky bluegrass was much more marked in 1936 than in 1937. Three factors may have contributed to the lower response in 1937, *viz.*, (a) the calnitro was applied seven days earlier in 1937; (b) the first cutting was made four days later; and (c) the first two weeks of May were cold and dry as compared with the same period in 1936.

The Rhode Island bent plats showed the same general tendency except for the variation caused by not mowing until June 1 in 1937. In that case, the greater maturity of the grass and the longer period of time elapsed since fertilization largely masked the effect of the April nitrogen on the nitrogen content.

Grass from plats receiving all their nitrogen in June had the highest total nitrogen in July, while the August nitrogen application had its maximum effect in September. The relatively high response to August nitrogen in 1937 was probably due to the abnormally high rainfall in late August and early September.

These results suggest the possibility of controlling the seasonal peaks in total nitrogen of the herbage by adding or withholding available nitrogenous fertilizers. In regard to yields, a similar suggestion was made by Brown and Munsell (1), who reported the results of a study of the effects of time and frequency of application of nitrogen on the yields of Kentucky bluegrass and Rhode Island bent grasses. They showed the possibility of delaying the peak of high production to mid-summer or even late summer by withholding the April or both the April and June application of nitrogen until June or August. However, it should be noted that relatively high amounts of nitrogen (56 pounds) were necessary to accomplish that change.

In the present experiment, regardless of number of applications of nitrogen per season, most of the effects of the nitrogen were reflected in the succeeding cutting. The second cutting after the application showed little or no effect. Mortimer and Ahlgren (3) concluded from their study of Kentucky bluegrass fertilization that high nitrogen content is produced only where frequent applications of nitrogen are made throughout the growing season. Similar conclusions were reached by Enlow and Coleman (2) from their study of Bahia, carpet, and centipede grasses in Florida.

At Storrs when three applications of nitrogen at 56 pounds each were made in April, June, and August, three successive peaks in total nitrogen content were produced. Each sharp rise occurred at the next cutting following applications, and even with this large amount of nitrogen, the effect of the fertilization disappeared within a month.

AMOUNT OF FERTILIZER

A third phase of the investigation was concerned with the variations in total nitrogen content of the two grasses when different amounts

of fertilizer were applied. The results of six applications of nitrogen per season at 14 pounds are also included in this section. Results are given in Table 6 and are shown graphically for Rhode Island bent grass in Fig. 4.

TABLE 6 —*Percentage of nitrogen in the dry matter of Kentucky bluegrass and Rhode Island bent grass as affected by amounts of calnitro*

Treatments*	Kentucky bluegrass, 1936						
	May 14	June 10	July 1	July 30	Aug 25	Sept 22	Nov 5
None	2 82	2 36	2 50	2 45	2 45	2 84	2 49
N/2 (15th Apr Sept)	3 16	2 61	2 47	2 56	2 48	2 90	3 28
N123	3 74	2 35	2 50	2 94	2 60	3 12	2 67
NN123	4 09	2 43	2 45	3 43	2 87	3 98	3 08
	1937						
	May 18	June 8	June 29	July 19	Aug 19	Sept 3	Oct 5
None	2 34	2 35	2 62	2 76	1 96	2 45	2 81
N/2 (15th Apr Sept)	2 58	2 68	2 94	3 39	2 81	3 78	3 16
N123	2 80	2 32	2 37	3 65	2 44	4 22	2 92
NN123	3 07	2 60	2 90	4 30	2 97	4 77	3 30

Treatments*	Rhode Island bent grass, 1936				
	May 18 19	June 16	July 22	Sept 14 16	Nov 3 5
None	2 85	2 20	2 19	2 32	2 24
N/2 (15th Apr Sept)	3 07	2 33	2 36	2 95	3 05
N123	3 49	2 19	2 63	3 13	2 47
NN123	3 83	2 43	2 98	3 52	2 63

Treatments*	1937					
	June 1	June 23	July 20	Aug 28	Sept 18	Oct 26
None	2 45	2 69	3 25	2 92	3 40	2 66
N/2 (15th Apr Sept)	2 35	3 07	3 00	2 96	3 55	2 74
N123	2 55	2 83	2 98	2 97	3 70	2 61
NN123	2 65	3 03	3 55	3 18	4 39	3 36

*N/2 = 14 pounds elemental nitrogen per application, N = 28 pounds elemental nitrogen per application; NN = 56 pounds elemental nitrogen per application 1 = applied in April, 2 = applied in June, and 3 = applied in August

The summary in Table 7 shows the average amount of variation in total nitrogen with change in rate of application of calnitro.

It is evident that calnitro applied in equal total amounts was equally efficient whether applied in three applications or in six monthly applications. However, the graphs show that the six monthly treatments maintained a somewhat more uniform nitrogen content throughout the growing season. While there were some fluctuations,

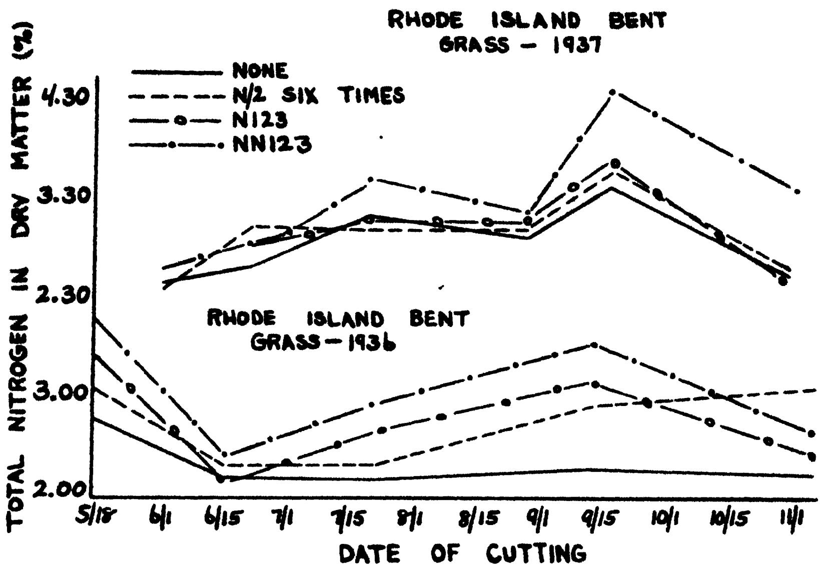

FIG. 4.—Percentage of nitrogen in the dry matter of Rhode Island bent grass as affected by the amount of calnitro applied, 1936 and 1937.

TABLE 7.—*Variation in total nitrogen with change in rate of application of calnitro.*

Pounds of N		Kentucky bluegrass		Rhode Island bent grass	
Per application	Per season	Total N (%), av. 2 years	Increase over no treatment	Total N (%), av. 2 years	Increase over no treatment
0	0	2.52	—	2.63	—
14	84	2.92	0.40	2.85	0.22
28	84	2.91	0.39	2.90	0.27
56	168	3.30	0.78	3.22	0.59

they were less extreme than where the calnitro was applied only three times per season.

When applications of calnitro were increased to add 56 pounds of actual nitrogen three times annually, the total nitrogen increased 0.39% in Kentucky bluegrass and 0.32% in Rhode Island bent over the 28-pound treatments.

RECOVERY OF NITROGEN

To secure some measure of the efficiency of the various nitrogen carriers and also of the different times and frequencies of application of calnitro, calculations were made of the recovery of nitrogen. In making these calculations, the amount of nitrogen recovered in the crop from the untreated plat was subtracted from the amount obtained in the treated plats.

In the first half of Table 8 are given the 2-year average percentages of nitrogen recovered for both grasses for the eight nitrogen carriers. The relative rankings are shown also. It is clear that the best recoveries were obtained from calnitro, calcium nitrate, nitrate of soda, and sulfate of ammonia. This was true of both grasses. In the second half of the same table are given the percentages of nitrogen recovered from applications of calnitro at different times during the season.

TABLE 8 — *Recovery of nitrogen (per cent).*

Treatments*	Kentucky bluegrass		Rhode Island bent grass	
	Two-year average	Rank	Two-year average	Rank
Sodium nitrate, N123	41	2	53	4
Ammonium sulfate, N123	40	4	53	3
Ammonium carbonate, N123	8	8	6	8
Ammonium chloride, N123	30	5	20	7
Calcium nitrate, N123	48	1	60	2
Cyanamid, N123	25	7	41	6
Urea, N123	25	6	46	5
Calnitro, N123	41	3	63	1
Calnitro, NN1	51	4	70	1
Calnitro, NN12	57	1	65	2
Calnitro, NN123	52	3	61	4
Calnitro NN2	51	5	59	5
Calnitro, NN23	48	7	57	6
Calnitro NN13	53	2	63	3
Calnitro NN3	34	8	45	7
Calnitro, N/2 (15th Apr.–Sept.)	50	6	44	8

*N/2 = 14 pounds elemental nitrogen per application, N = 28 pounds elemental nitrogen per application, NN = 56 pounds elemental nitrogen per application 1 = applied in April, 2 = applied in June, and 3 = applied in August

In this comparison the largest recoveries were obtained with both grasses when the treatments included an application of nitrogen in April. August nitrogen was the least efficient, with June applications intermediate This fact also corroborates the data on yields obtained in another experiment.

SUMMARY

A study of the effects of various sources of nitrogen and frequencies and rates of application of calnitro on the nitrogen content of Kentucky bluegrass and Rhode Island bent grass was made for 1936 and 1937. The results are summarized as follows.

1 Of eight nitrogen carriers applied to pure stands of Kentucky bluegrass and Rhode Island bent grass, ammonium carbonate alone failed to give significant increases in total nitrogen over the untreated plats. In this respect there were no appreciable differences between the other seven sources of nitrogen.

2. The data on frequency of application of calnitro show that marked increases in total nitrogen in both grasses occurred only in the first cutting after the fertilizer was applied. After about a month, the influence of the calnitro was no longer manifest.

3. A single application of nitrogen in April produced its greatest effect in May, after which the nitrogen content fell rapidly and remained low for the rest of the season. By withholding the fertilizer until June or August, the highest point in total nitrogen for the season was reached in the succeeding cutting. However, a relatively high rate of nitrogen application (56 pounds) was required to attain this end.

4. In regard to amount and frequency of applying nitrogen, 14 pounds applied, six times during the season produced practically the same increase in average nitrogen content over no treatment as three applications of 28 pounds. However, there was less fluctuation when applications were made six times per season. When 56 pounds of nitrogen were applied three times (168 pounds per season), further increases of 0.39% in the case of Kentucky bluegrass and 0.32% in the case of Rhode Island bent were obtained in the average contents of nitrogen.

5. The percentage recoveries of nitrogen indicated that calnitro, calcium nitrate, ammonium sulfate, and sodium nitrate were more efficient than the other four carriers. When calnitro was applied at different times during the season, the greatest recovery was obtained from the plats receiving nitrogen only in April. August nitrogen was the least efficient, with June intermediate.

LITERATURE CITED

1. BROWN, B. A., and MUNSELL, R. I. Pasture investigations (eighth report): Modifying the seasonal growth habits of grasses. Storrs (Conn.) Agr. Exp. Sta. Bul. 209. 1936.
2. ENLOW, C. R., and COLEMAN, J. M. Increasing the protein content of pasture grasses by frequent light applications of nitrogen. Jour. Amer. Soc. Agron., 21:845-853. 1929.
3. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation and stage and height of cutting on yield and composition of Kentucky bluegrass (*Poa pratensis* L.). Jour. Amer. Soc. Agron., 28:515-533. 1936.
4. Official and Tentative Methods of Analysis of the A. O. A. C. Ed. 3, 1930. (Chapter II, paragraphs 22 and 19.)

PASTURE YIELDS AND CONSUMPTION UNDER GRAZING CONDITIONS[1]

R. F. FUELLEMAN AND W. L. BURLISON[2]

INVESTIGATIONS of pasture yields and consumption under actual grazing conditions have been carried on for a number of years at the Illinois Experiment Station. Although a vast amount of experimental research in pastures and pasture plants has been and is being performed at the various experiment stations in this and foreign countries, it is usually conceded that specific results are broadly localized depending upon a number of ecological factors. This means that within the confines of a rather restricted area the farmers feel that they must depend upon the experimental results of their own local and state experiment stations.

Practical information relative to pastures, pasture plants, and utilization is demanded by farmers in ever-increasing number. The motivating forces behind this demand, economic or otherwise, have brought forward the very pertinent fact that the agricultural industry as a whole is vitally interested in pastures and pasture improvement. The hackneyed phrase that "The most economical source of nutrients is good pasture," is true for most types of livestock, and the proper utilization of pasturage is important to the success of any livestock enterprise. The demand for information previously mentioned has forced the investigation of many problems, some old and some new.

The practical evaluation of pastures presents a problem in itself of large proportions. There are many methods in use, but no single one has found general use in this country. Lack of uniformity in methods can be ascribed to the wide range of variable ecological and topographical conditions necessitating modifications and changes in technic. The most popular method in use for measuring yields is that of clipping to simulate grazing Like all methods it is, of course, open to criticism for obvious reasons, but at the present time there apparently is no better method except the measurement of pastures by the use of grazing animals or combinations of clipping and grazing.

The method used in evaluating pasture yields and consumption at Illinois is a modification of that recommended by the Pasture Committee of the American Society of Agronomy. The latter method does not presume to measure consumption directly but rather bases its measure of consumption upon gains in live weights and in animal products. The method as used at this station measures yields by clipping of sample areas as well as by the differences between growth and consumption. The total growth, total consumption, and the residual growth are obtained at the same time. This method is open to criticism particularly from the standpoint of the necessity of

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[2]Research Assistant and Head of Department, respectively. Acknowledgment is made to V. G. Sprague for assistance in securing data in 1936.

selecting so-called "judgment samples." Restrictions of time and expense prevent the use of random sampling.

This paper presents some of the agronomic data and observations from a cooperative project with the Animal Husbandry Department. These data are from the experimental farm pastures at Urbana, Illinois.

METHODS

In 1929 and the succeeding years to 1935, inclusive, a number of 5- and 10-acre fields on the South Animal Husbandry Farm at Urbana, Illinois, were seeded to pasture grasses and legumes. These have included brome grass, *Bromus inermis;* reed canary grass, *Phalaris arundinacea;* orchard grass, *Dactylis glomerata;* Kentucky bluegrass, *Poa pratensis*, and alfalfa, *Medicago sativa*. A number of mixtures were seeded, but the data from these fields are not complete at the present writing.

Brome grass was seeded in mixture with redtop and Kentucky bluegrass, but the dominant vegetation is bromegrass at the present time. Reed canary grass was seeded in the spring of 1935 on a 5-acre field. A small stream drains through this field, but it has an elevation equal to the surrounding crop land. A good stand was secured and it is still a practically pure field of reed canary grass. Kentucky bluegrass has been seeded on several fields and four of these were originally used in these experiments. At the present time two of these pastures are being used for yield and consumption data. Alfalfa was seeded on one 10-acre field in 1934, but data are presented for only one year.

As stated previously, methods of sampling pastures under grazing conditions have not been well developed and the method used here varies with the experimental plan and according to the best judgment of the operators, keeping in mind the fact that accurate and practical results are desired. When the number of samples taken are limited by labor and expense restrictions, it is necessary to take as many samples as possible using judgment in making the selection. This, of course, introduces the possibility of error. But the person making the selection of representative areas soon acquires sufficient experience to enable him to take samples without the introduction of excessive error. However, as different portions of the same pasture vary from each other, so may there be variation among the samples representing an area.

Metal cages were used to protect the sample areas from grazing (Fig. 1). The cages were constructed from $\frac{3}{8}$-inch iron rods welded together to form a frame 4 x 4 feet square by 18 inches high. The corner rods extended 12 inches beyond the bottom of the cage and provided anchorage. The top and sides were covered with heavy 2 x 6 inch mesh woven wire welded to the frame.

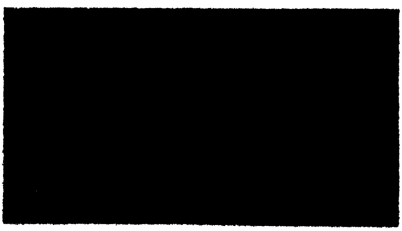

FIG. 1.—Type of metal cage used for protection of sample areas.

A definite procedure was followed in placing the cages. The pastures were divided by imaginary lines into three parts and one set of two cages placed in each part. Three samples were taken from each section of the field on each sampling date. They were designated as "A", "B", and "C", and the different sections of the field designated as 1, 2, and 3, so that samples from the first section would be designated as "1A", "1B", and "1C". The "A" sample consisted of herbage plucked or clipped from beneath a cage which had been placed over a representative grazed area at a previous sampling date or when the cattle were turned in. The sample harvested from a representative grazed area was designated as "C", while sample "B" was composed of the herbage which was harvested from beneath the cage placed on the "C" area on the previous sampling date. "B" is the total growth since the previous sampling date.

The method of harvesting varied to some extent with the growth. Whenever possible, plucking was resorted to but when the material became coarse and tough a grass knife was used.

The harvested herbage was placed in loose cotton bags with proper labels to show their origin. The samples were then weighed and recorded. Then all the "A" samples, "B" samples, and "C" samples respectively from each field were composited and run through a grinder which reduced them to a uniformly small size. From the composited material a sample was taken for air- and oven-dry forage measurements and for chemical analyses. Air drying was accomplished in an oil burner equipped drying house which was heated to 55° to 60° C, reducing the moisture content of the material to approximately 4 or 5%. For oven-dry weights a thermostatically controlled electric oven was used in which the temperature was held at 98° to 100° C. The samples for chemical analysis were placed only in the drying house. From the oven-dry weight the percentage dry matter was calculated.

The use of the "A", "B", and "C" samples gives a measure of the consumption and production of forage. Two methods were used, in making the estimates of yields and consumption, one the "A-C" method and the other the "B-C" method. In this paper the results of the two methods are averaged for in general this average gives a more accurate and uniform picture of the results.

CLIMATIC FACTORS

Yields as well as consumption of forage are very markedly affected by rainfall and temperature. Yield curves have a tendency to parallel rainfall curves, but consumption curves ordinarily do not fluctuate widely during the fore part of the grazing season. There is a tendency on the part of livestock, however, to graze more heavily during the latter part of the season, usually beginning about the first of September. This trend can be ascribed to several things, namely, more moderate temperatures, an increase in rainfall, decrease in troublesome insects, and what may be most important, an apparent increase in palatability.

The growing season of 1935 at Urbana, Illinois, was marked by an abundance of well-distributed rainfall accompanied by moderate

temperatures. Yields and consumption were much greater than during the following season of 1936, which was the reverse of 1935. Rainfall was deficient in June and July of 1936 and temperatures were excessively high. Fig. 2 illustrates graphically total weekly precipita-

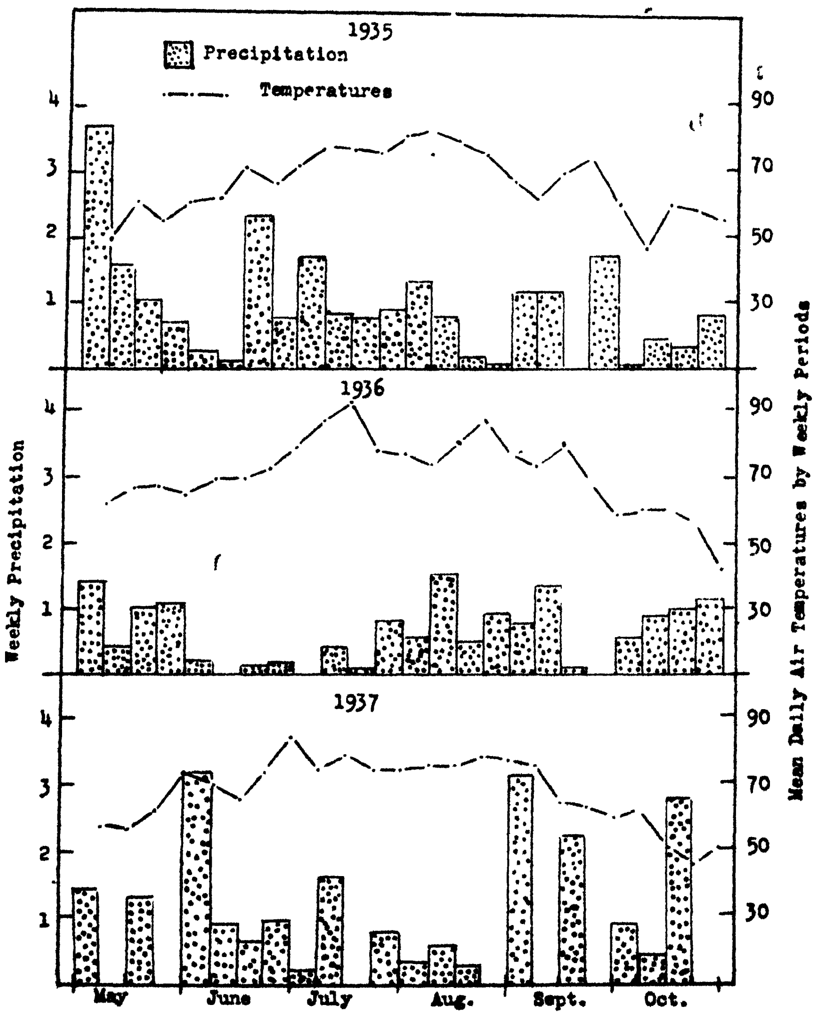

FIG. 2.—Graphs illustrating total weekly precipitation and average daily temperatures by weekly periods for the grazing season of 1935, 1936, and 1937.

tion and average daily temperatures by weekly periods for the growing seasons of 1935, 1936, and 1937. In 1937 the growing season was more nearly normal with respect to precipitation and temperature. Precipitation, with the exception of the latter part of August, was sufficient and the temperatures not excessively high.

DISCUSSION OF RESULTS

This discussion does not include results obtained from all fields used in the experimental setup but chiefly those dealing with pasture species considered of greater importance in this area.

KENTUCKY BLUEGRASS

Kentucky bluegrass, *Poa pratensis*, because of its adaptability, persistence, and aggressiveness is used for pasturage more than any other species, but this grass has several serious deficiencies which restrict its yield, consumption, and apparent palatability. One of these is early maturity. It begins growth very early in the spring and produces seed culms and seed during the latter part of May or early June. Its period of greatest apparent palatability is in late March and during April, usually before it is feasible to turn livestock out to graze. A second peak in consumption occurs in mid-August or early September, depending upon precipitation and temperature. The second deficiency of Kentucky bluegrass and perhaps the most important from the pasture standpoint is summer dormancy. Yields of forage declined during mid-summer periods of 1935, 1936, and 1937. However, the trend of production usually levels off or swings upward in the early fall Fig. 3 illustrates the yields and consumption of forage on Kentucky bluegrass fields for 1935, 1936, and 1937

Consumption in 1936 was relatively higher than in 1935 Livestock consumed 85% of the forage available in 1936 as compared with approximately 65% of the forage available in 1935 In 1937 consumption approximately equaled production, but referring to Fig. 3 it will be noted that grazing was continued until November 15. Photosynthetic activity on the part of the plant had practically ceased previous to this date as is evidenced by the yield trends illustrated in Fig. 3 and in Table 1.

Table 1 shows that in 1935, 61% of the total seasonal yields was obtained by June 21 and 83% by July 19. In 1936, 62% of the yield was obtained by May 22 and 84% of the total seasonal yield by June 19, exactly one month in advance of the previous year's 83% mark. The difference is, of course, due to the fact that the total 1936 yield was approximately only 50% of the 1935 yield. The point illustrated by these percentages merely indicates that the first two months of the grazing season usually furnish more than 60% of the season's total forage. Consumption is more nearly equalized throughout the grazing season.

ORCHARD GRASS

Orchard grass, *Dactylis glomerata*, like Kentucky bluegrass, starts growth early in the spring and matures at approximately the same time as the latter. In its ability to yield it compares very favorably with bluegrass. It has several favorable characteristics which make it desirable in pastures. In addition to its early growth, it is apparently quite palatable to cattle and sheep during the fore part of the grazing season and also in the latter portion of the season. It is a shade grass and yields well under shade conditions and usually remains green

TABLE 1.—*Growth and consumption of Kentucky bluegrass for 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
Apr. 26	1,824	28	0
May 24	961	42	825
June 21	1,229	61	893
July 19	1,351	83	643
Aug. 13	445	90	500
Sept. 11	695	—	1,402
Total	6,505	—	4,263
	1936		
Apr. 24	876	25	0
May 22	1,435	62	532
June 19	509	84	582
Aug. 1	−128	—	1,267
Aug. 29	463	94	461
Sept. 26	228	—	70
Total	3,383	—	2,912
	1937		
May 4	880	18	0
June 1	1,469	48	293
July 20	909	66	509
Sept. 3	928	85	2,825
Nov. 15	721	—	1,282
Total	4,908	—	4,908

under moderate drouth conditions. Consumption is rather uniform throughout the grazing season, particularly if the season is dry or approximately normal. An abnormally wet season causes the growth to be large and stemmy, thus lowering consumption. Consumption in 1935 was 90% of production, but in 1936 it was approximately 99%. In 1937 it was 93%. If these figures are a criterion, then orchard grass must be relatively palatable. Fig. 4 illustrates the growth and consumption trends. Table 2 presents the growth and consumption data in tabular form.

In 1935, 76% of the total yields occurred before July 20. The total yield for the season was slightly less than that of bluegrass, but like bluegrass its productivity is greatest in the cool fore part of the growing season. As previously stated, orchard grass begins growth early in the spring and matures shortly after Kentucky bleugrass. In 1936 the effect of heat and drouth are distinctly apparent, particularly as it has affected productivity, but the percentage of the total yield on any given date approximates that of the previous year. The total yield for 1936, as well as 1937, exceeded that of Kentucky bluegrass,

a difference possibly attributal to temperature As in 1935 and 1936 a high percentage of the total yield is accounted for previous to mid-July.

KENTUCKY BLUEGRASS

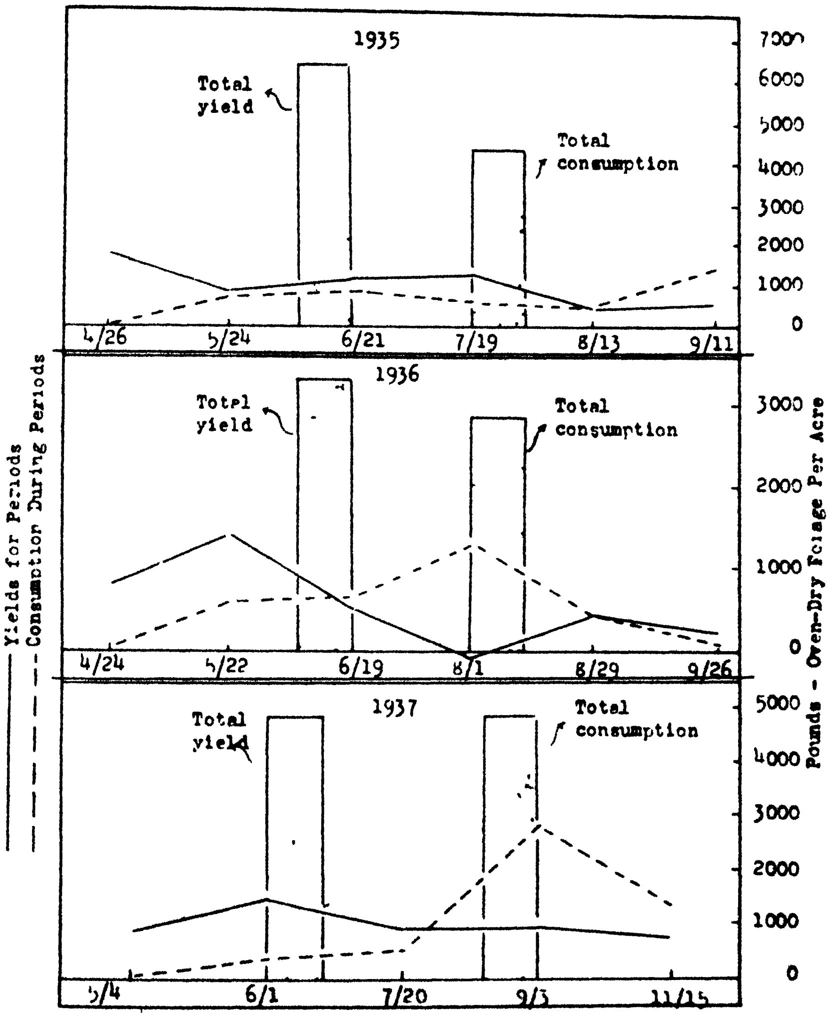

FIG 3 —Graphs illustrating yields and consumption of Kentucky bluegrass for the years 1935, 1936, and 1937

BROME GRASS

Brome grass, *Bromus inermis*, has been used in these experiments as a pasture for sheep since 1934, but yield and consumption data are presented only for 1935, 1936, and 1937

Considerable interest has been evinced in this grass not only because of its yielding ability but because of its apparent palatability and nutritiousness. It has proved to be drouth and heat resistant under Urbana conditions, remaining green and palatable in 1936

TABLE 2.—*Yield and consumption of orchard grass, Dactylis glomerata, in 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
Apr. 26	1,799	31	0
May 24	1,676	43	1,595
June 12	475	52	388
July 19	1,396	76	1,678
July 26	613	87	608
Aug. 23	100	88	--
Sept. 17	236	93	—
Oct. 15	426	—	852
Total	5,721	–	5,079
	1936		
May 27	1,897	49	0
June 26	699	67	931
July 21	−47	—	920
Aug. 24	641	83	1,010
Sept. 25	261	90	508
Nov. 11	601	–	615
Total	3,864	--	3,804
	1937		
May 4	1,236	23	0
June 7	2,379	67	576
July 1	427	75	1,096
July 29	925	92	992
Aug. 16	146	93	648
Sept. 15	458	—	277
Oct. 23	−208	—	1,469
Total	5,371	—	5,009

when Kentucky bluegrass became dormant and orchard grass was apparently unpalatable. The consumption in 1935 was 90% of the yields and likewise in 1936. The number of sheep pastured on the brome grass field in 1936 was reduced to prevent over-grazing and injury to the grass. In 1937 the consumption data are not complete. The sheep grazing this field were being used as part of a comparative test and were removed between July 29 and October 30, after which a number of Hereford cattle grazed until November 17. Consumption was 79% of yields, but it can be assumed that the long period of disuse in September and October accounts for this rather low consumption. Yield and consumption data are tabulated in Table 3. Fig. 5 illustrates the data by means of graphs.

Seasonal productivity of brome grass is similar to that of bluegrass and orchard grass However, the seed matures considerably later than that of either of the former species In 1935 the productivity on June 21 was 67% of the seasonal total In 1936, on approximately the same

ORCHARD GRASS

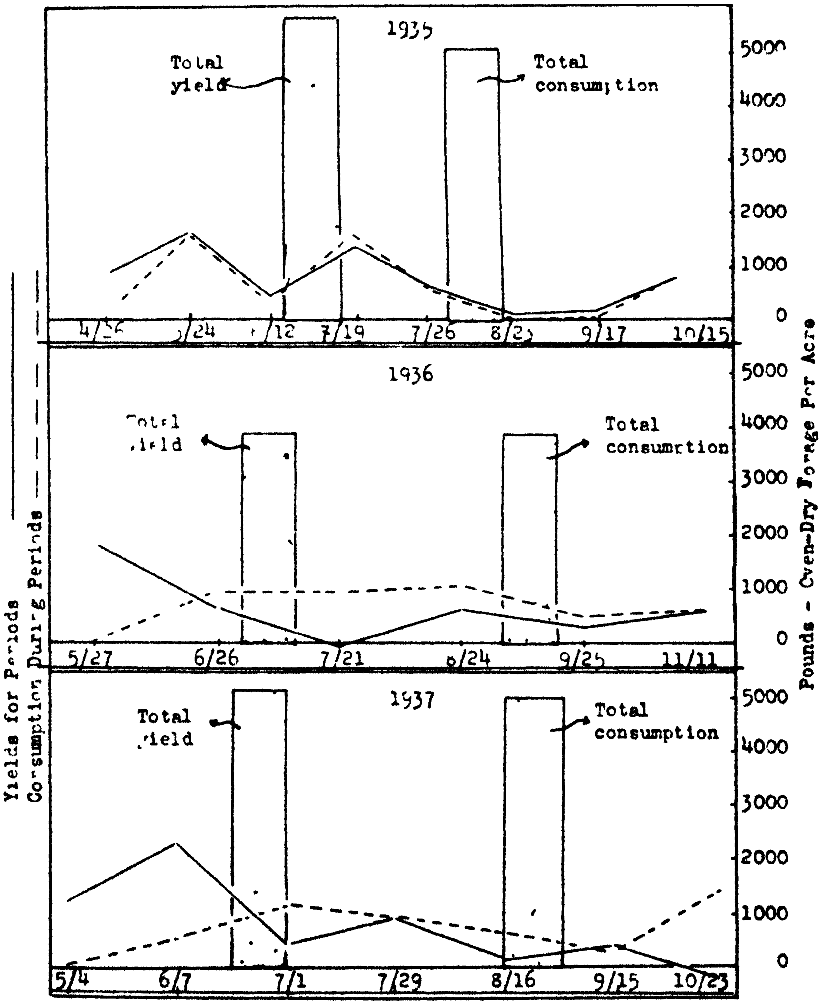

FIG 4 —Graphs illustrating yield and consumption of orchard grass, *Dactylis glomerata*, in 1935 1936 and 1937

date it was 81% of the total, but in 1937 it was 73% of the total on July 1. The table gives some indication of the much greater productivity of brome grass. The percentages of the total production, particularly in 1936, also show that after July 1 the high temperatures

and lack of rainfall had a restraining effect upon yield or growth as the balance of the grazing season produced only 19% of the seasonal total.

TABLE 3.—*Yield and consumption of brome grass, Bromus inermis, during the growing seasons of 1935, 1936, and 1937.*

Sampling date	Yield for period, lbs per acre	Total growth, %	Consumption for period, lbs. per acre
	1935		
May 3	2,196	23	0
May 24	1,642	41	1,392
June 21	2,416	67	1,764
July 19	1,381	82	1,654
Aug. 30	1,450	98	2,108
Sept. 27	188	—	1,590
Total	9,273		8,508
	1936		
May 1	1,252	26	0
May 26	1,579	59	0
June 26	1,045	81	301
July 21	-468		1,428
Aug. 24	894	90	1,433
Sept. 15	457	—	1,233
Total	4,759	—	4,395
	1937		
May 4	1,194	17	0
June 8	3,118	59	1,976
July 1	913	74	596
July 29	1,717	98	1,645
Aug. 16	184	99	0
Oct. 30	133	99	0
Nov. 17	194	—	1,355
Total	7,066	—	5,572

REED CANARY GRASS

Reed canary grass has usually been considered to be best adapted to low land subject to periodic overflow. In the spring of 1934 a 5-acre field was seeded to reed canary grass. This field has approximately the same elevation as the surrounding farm land. It was used as a pasture for cows in 1935, and for pasturing Hereford steers in 1936 and 1937. Yield data are available for the latter years (Table 4).

Yield curves (Fig. 6) are similar to those of orchard grass and bluegrass in that a large percentage of the yield is produced early in the season and it is during this period that the grass is most palatable. However, the cattle were not turned in this pasture until May 26, 1936.

The results in terms of consumption have come largely in July and August at the time when reed canary grass is considered less palatable.

In 1936 it furnished a large quantity of forage when other pastures were not productive. However, a large percentage of this forage was carried over from the preceding months. In 1937 cattle were not

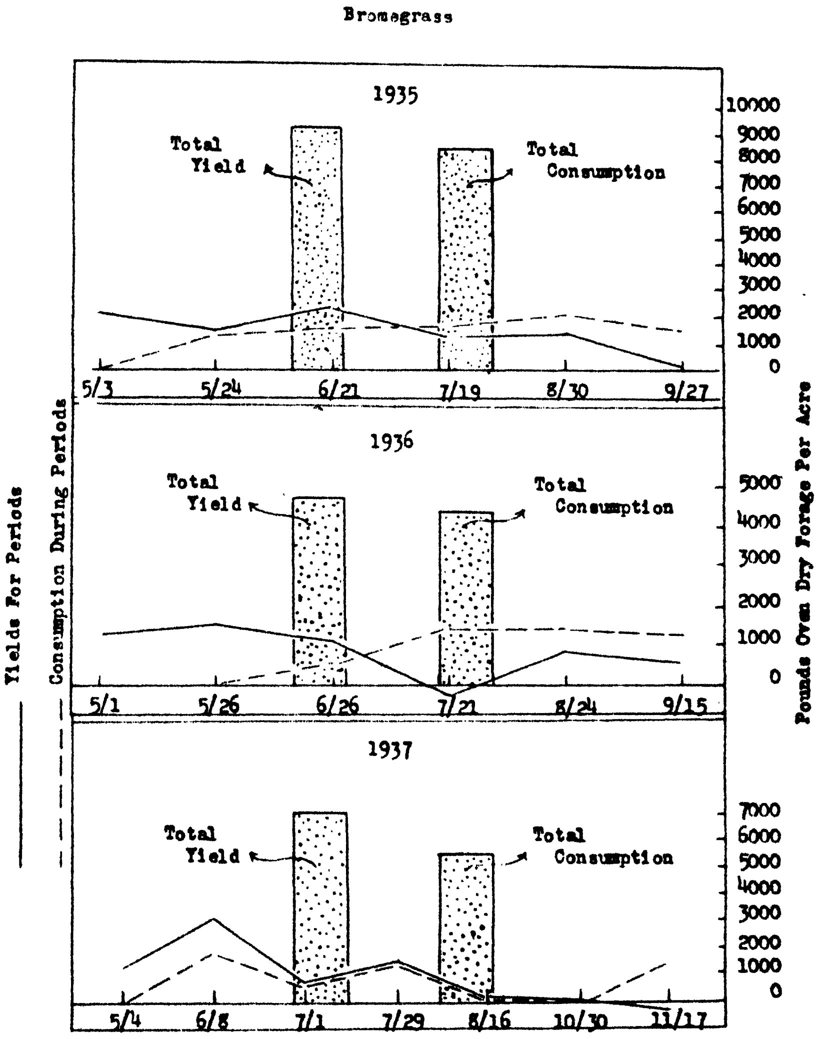

FIG. 5.—Yields and consumption of brome grass, *Bromus inermis*, during growing seasons of 1935, 1936, and 1937.

turned into the canary grass until June 23. The trend of production paralleled that of 1936, however consumption in 1937 was very low. This is presumably the result of previous management of the livestock, although any one of a number of factors may be responsible for this decline.

TABLE 4.—*Yield and consumption of reed canary grass, Phalaris arundinacea, in 1936 and 1937.*

Sampling date	Yield for period, lbs per acre	Total growth, %	Consumption for period, lbs. per acre
	1936		
May 26	2,323	43	0
June 26	1,364	68	451
July 21	194	72	2,400
Aug. 24	859	88	1,390
Sept. 15	663		504
Total	5,403		3,843
	1937		
May 4	1,000	22	0
June 17	2,390	77	0
June 23	512	89	0
July 16	1,161		405
Aug. 13	446		679
Sept. 13	539		558
Oct. 30	773		1,346
Total	4,385	—	1,872

ALFALFA

The results of the grazing period of 1935 were available and are included (Table 5) because they show some rather interesting points

TABLE 5.—*Yield and consumption of alfalfa in the grazing season of 1935.*

Sampling date	Yield for period, lbs. per acre	Total growth, %	Consumption for period, lbs per acre
May 3	2,550	26	0
May 24	996	36	909
June 21	1,647	53	2,206
July 19	1,157	65	1,834
Aug. 30	2,667	93	2,331
Sept. 27..	638	—	1,351
Total	9,655	—	8,631

Yields were high as well as consumption, but it should be noted that the yields and consumption were rather uniformly distributed throughout the growing season. This is in contrast to the fluctuating yields of the grasses. The grasses produce a larger proportion of their annual yield in the first two months of the grazing period than does alfalfa. The grasses are for the most part cool weather plants and are adapted to greater productiveness during the cool portion of the grazing season. As temperature increases grass production tends to decrease. Temperature is apparently more important than moisture, especially during the fore part of the grazing season. This is true of

the later months of the grazing season also, but during this latter period moisture is equally important. However, alfalfa as is illustrated in Fig. 7, produced approximately one-half of its total growth at the mid-season grazing point.

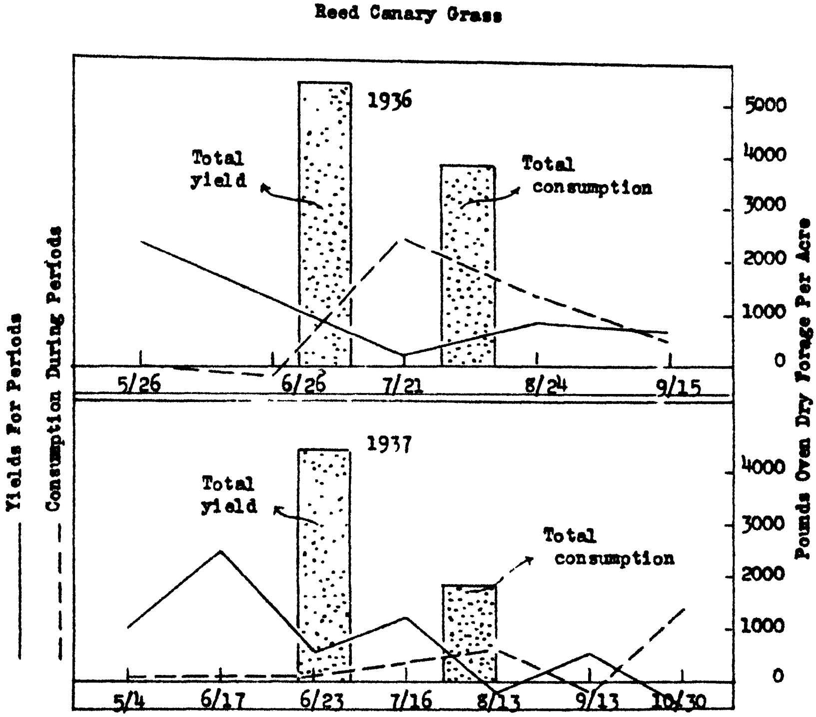

FIG. 6 – Yields and consumption of reed canary grass, *Phalaris arundinacea*, for growing seasons of 1936 and 1937

SUMMARY

Data are presented showing calculated yields and consumption of pasturage at Urbana, Illinois.

The yield curves of pasture grasses parallel rather closely precipitation curves but are the reverse of temperature curves; when temperature increases the tendency for grass yields is to decrease. Alfalfa is rather uniformly productive throughout the grazing season.

Kentucky bluegrass has been used frequently as a basis of comparison with other grasses, and although it may have some serious defects, there is little likelihood that it can be equalled for general adaptation, utility, and persistence.

Brome grass persistently out-yielded all the other grasses used for pasturage at this station during 1935, 1936, and 1937. It apparently has a high degree of palatability as indicated by a comparison of the curves of consumption and production. In addition to its yielding capacity and apparent palatability, it has persisted remarkably well,

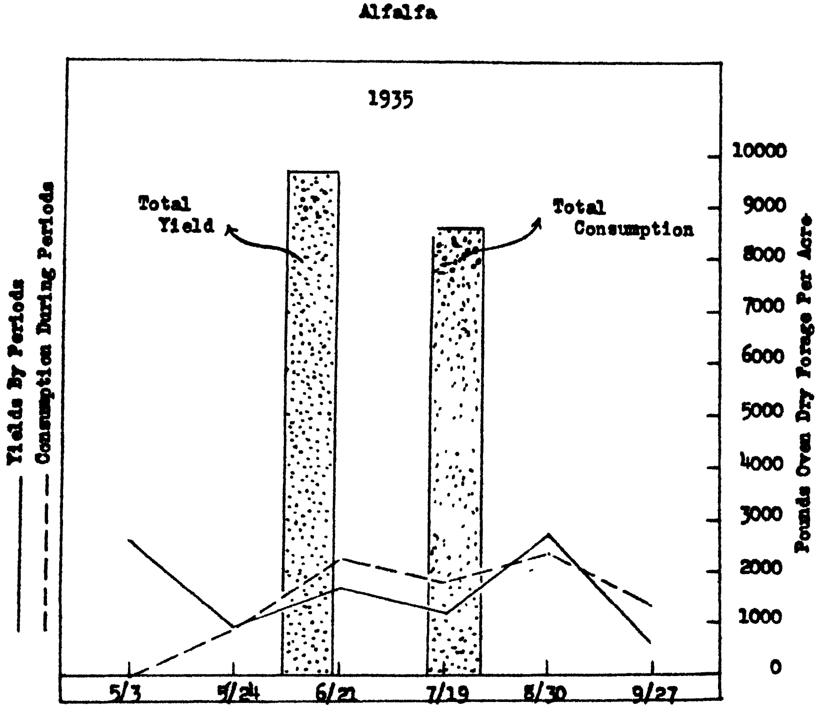

FIG. 7.—Yield and consumption of alfalfa for the growing season of 1935.

Orchard grass has given very good results, particularly in the light of its frequent indictments for unpalatability. If growth and consumption are a criterion of palatability, then orchard grass seems to rank almost equally with Kentucky bluegrass, long considered the standard for comparison.

Reed canary grass is not relished by cattle, particularly when it becomes stemmy. Indications point to a restricted use for pasturage, particularly on land adapted to other pasture crops. However, it has a place both as a hay and pasture plant on land subjected to periodic inundation.

VEGETATIONAL CHANGES AS A RESULT OF FURROWING ON PASTURE AND RANGE LANDS[1]

CHARLES J. WHITFIELD AND CLAUDE L. FLY[2]

THROUGHOUT the Southern Great Plains, overstocking, drought, and erosion have slowly deteriorated the range and pasture lands. The original vegetation was dominated by grasses which formed a dense sod that effectively prevented erosion. Now this plant cover has changed; much of the grass has been replaced by cactus and weeds. In 1934 when the Soil Conservation Service began operations, many pastures and much of the range land throughout Region Six,[3] which included the so-called "dust bowl", had insufficient cover to prevent the soil materials from being blown or washed away.

With the initiation of the program for erosion control, work was immediately started to improve the pastures and range land by mechanical treatment and regulated grazing By mechanical treatment is meant the use of machinery in treating lands so that moisture will be retained where it falls. Runoff water is caught and held by the contour furrow or ridge, thus reducing flood and erosion damages and adding to the soil moisture supply. The increased water supply in turn changes the composition, volume, and density of the vegetation

The most common method of treatment in use is contour furrowing Other practices which are often used are ridges, pasture and range terraces, diversion structures, and water-spreading systems The furrow is made by "a single through" with a lister, plow, or chisel, with the furrows far enough apart to prevent the furrow-slices meeting. The ridge is constructed by using a lister, blade, or disc in such a manner as to bring the furrow-slices together In making the pasture terrace a number of furrow slices are thrown together to increase the terrace ridge to the desired height and cross-section. The furrow, the ridge, and the terrace are designed to hold water on the ground and may be used in different combinations with relation to each other. Diversion structures are used to divert water from points of concentration and spread it over areas where it will be available for more effective utilization by plants. A combination of diversion structures, furrows, and ridges is most efficient in using flood water in plant production.[4]

On the project at Dalhart, Texas, a study of pasture furrowing was made on a heavy sandy loam soil. In order to check the effects of furrowing, an exclosure was established. Half of the exclosure was treated, the other half was left untreated. The work was done during the first part of May, 1937. Vegetational measurements were taken in

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[1]Contribution from the Soil Conservation Service, U. S. Dept of Agriculture. Received for publication January 16, 1939.

[2]Soil Conservationist and Associate Soil Scientist, respectively.

[3]Region Six, of the Soil Conservation Service is composed of parts of five states, Colorado, east of the Continental Divide, Kansas, eastern New Mexico, and the panhandles of Oklahoma and Texas.

[4]Acknowledgment is hereby made to Fred C. Newport, Agronomist, Region 7, Soil Conservation Service, for his aid in the development of this paper.

October, 1937, and it was found that on the treated area approximately three times as much growth had developed as on the untreated portion. The most striking vegetational change, however, was in the

FIG. 1.—Profile of heavy clay loam soil on Hereford Project showing shallow penetration of moisture on an untreated area. Three inches of water applied in 1 hour by an artificial rainfall apparatus resulted in a runoff loss of almost 2 inches.

FIG. 2.—Profile of a heavy clay loam soil on Hereford Project showing effect of furrowing on moisture penetration. The furrows were 8 x 4 inches placed 7 feet apart. This system retained 2 inches of 3 inches of water applied in 1 hour by means of an artificial rainfall apparatus.

composition of the cover. Sand blue-stem, *Andropogon hallii*, is relatively abundant at the present time on the treated portion, whereas no sand blue-stem is found on the untreated area; side-oats grama,

Bouteloua curtipendula, was more conspicuous, with blue grama, *Bouteloua gracilis*, less so. The changes that have occurred indicate a rather strong trend toward the original type of vegetation that formerly occupied the soils of the region

To date small furrows varying from 4 to 8 inches wide and 4 to 8 inches deep have given the quickest and heaviest vegetational response in Region Six of the Soil Conservation Service. On the project at Hereford, Texas, a pasture was furrowed the latter part of April, 1937. A three-row lister, with the middle beam removed, was used to make pairs of furrows which were spaced 14 feet apart. The moldboards of the lister were removed, the points clipped, and the beams adjusted to make a furrow approximately 8 inches wide and 4 inches deep. Runoff studies made with an artificial rainfall apparatus showed that this type of furrow placed 7 feet apart on a clay loam soil of 3% slope was capable of holding 2 inches of a 3-inch rain applied in 1 hour when the soil was dry at the beginning of the test. An adjacent untreated area lost 2 inches of the three applied. The two plats were cross-sectioned 48 hours after the water was applied and photographs made of the distribution of moisture in the soil. As shown in Figs. 1 and 2, the moisture penetrates deeply in the furrow and forms a reservoir upon which adjacent growing plants may feed, while penetration is uniformly shallow on non-furrowed land Small, closely spaced furrows tend to distribute soil moisture more evenly, and therefore give quicker revegetation of the disturbed area, together with increased production of grass

To measure accurately the effectiveness of these furrows, grass was harvested from representative areas on both the furrowed and unfurrowed portions of the pasture Data were taken the first week in October, 1937. Harvesting was done by hand in such a manner as to simulate close grazing The yield on the furrowed portion was at the rate of 1,761 pounds of air-dried grass per acre and on the unfurrowed, 704 pounds per acre This was an increase of 1,057 pounds per acre.

On the Cheyenne Wells Project, furrows 5 inches wide, 4 to 5 inches deep, and 4 feet apart were constructed in April, 1937 (Fig. 3). Runoff studies on these treated areas showed that they retained 70% more water out of 3 inches applied in 1 hour by an artificial rainfall apparatus than an adjacent untreated area. Moisture tests made in September indicated 1.4 inches more soil-stored water in the treated plat. Rainfall was only 7.36 inches during the period of April to September.

Measurements made in October on the treated area showed an average density of 9.48% for buffalo-grama and 0.17% for forbs, while on the untreated range there was an average density of 4.8% for buffalo-grama and 0.54% for forbs (Fig. 4).

State and federal experiment stations are conducting similar investigations. Contour listing of native grassland was started at the Texas Agricultural Experiment Station at Spur, Texas, in 1932, and extended in 1934 and 1936.[5] The original work in 1932 was done on a

[5]Data concerning the Spur studies were supplied by R E. Dickson, Superintendent, and B. C. Langley, Technician, Texas Agricultural Experiment Station, Spur, Texas.

typical west Texas pasture lot where prickly pear, mesquite brush, and weeds had largely replaced the nutritious grasses. Results show that the yield, stand, and palatability of the forage have been in-

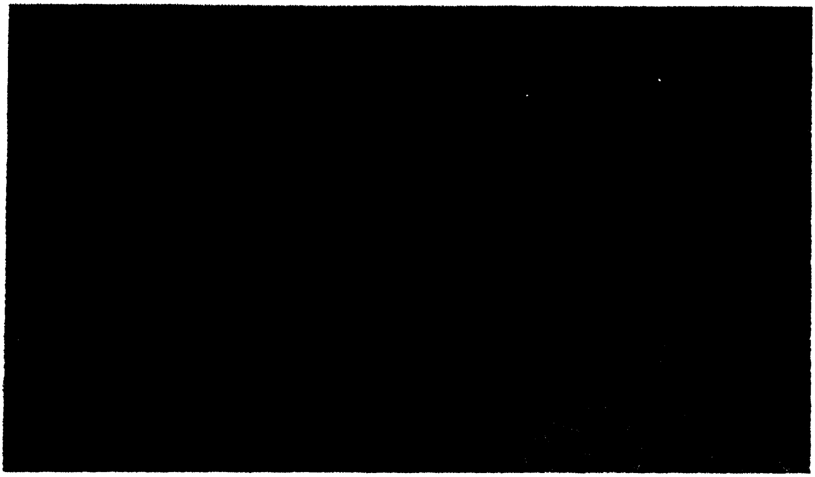

FIG. 3.—Type of pasture and range land treated in the spring of 1937 on the demonstrational project near Cheyenne Wells, Colorado.

FIG. 4.—Vegetational response as a result of trench furrowing pasture and range lands near Cheyenne Wells, Colorado.

creased by listing. At present the more important grass species are buffalo, blue grama, purple three-awn, and tobosa, the latter two species having decreased in density while the former two have in-

creased. Prior to listing, blue grama occurred only to a limited extent. The effect of contour listing on yield per acre of native grass pasturage is shown by the fact that there was an average of 2,369 pounds of air-dried hay per acre on listed land and only 725 pounds on unlisted land.

Other interesting observations at the Spur station are as follows: (1) The forage on the contour-listed areas was more palatable, as indicated by the more luxuriant growth; (2) fewer forbs occurred on areas where a good stand of grass has become re-established; (3) heavy rains in September, 1936, increased the total yield of forage about 20%.

In Region Six it has been noted that livestock generally graze along the furrow, and that the grasses stay green longer in and around the furrows than in the untreated portions. If furrowing is done in the fall there will be more weeds along the furrow than if treatment is made in the spring. Grasses give the best response when the range is furrowed in the spring. In some cases it appears that grasses have a tendency to crowd weeds from the furrows the second growing season. On sharp ridges above a foot in height there is a slower recovery of the more desirable grasses, due to the rapid drying out of the topsoil and unfavorable position for retention of runoff on the ridge.

RESPONSE OF CERTAIN PERENNIAL GRASSES TO CUTTING TREATMENTS[1]

C. M. Harrison and C. W. Hodgson[2]

IN the management of perennial grasses for forage purposes, it is important to know the effects of partial and complete defoliation upon the yield of top growth and upon the root development of these grasses. While grasses do not respond in precisely the same manner to grazing in the field by animals as they do to clipping in the greenhouse, results of such clipping trials furnish a valuable indication as to how the grasses may respond to varying amounts of defoliation under grazing practices. The present paper deals with the effects of weekly cutting at different heights on the yields of tops and underground parts by some of the more common perennial grasses in Michigan.

Frequent and close clipping of the tops of a grass reduces the amount of roots produced and the total yield of tops. When grass plants are completely defoliated, new top growth is initiated, in a large measure, at the expense of previously deposited root reserves. Unless these reserves are sufficiently replenished during the periods between successive cuttings, a reduction in reserve content of the roots occurs, which progressively diminishes the amount of new top and root growth following each cutting to the point of extinction

Dexter (2),[3] Graber (3, 4), Graber, *et al.* (5), Harrison (6, 7), Leukel and Coleman (8), Leukel, *et al* (9), Mortimer and Ahlgren (10), Pierre and Bertram (11), Robertson (12), Sprague (14), and Sturkie (15) give the effects of various cutting treatments on the yields of tops and underground parts of quack grass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis alba*), fescue (*Festuca rubra fallax*), timothy (*Phleum pratense*), Colonial bent grass (*Agrostis tenuis*), Bahai grass (*Paspalum notatum*), Centipede grass (*Eremochloa ophiuroides*), Carpet grass (*Axonopus compressus*), Kudzu (*Pueraria thunbergiana*), blue grama (*Bouteloua gracilis*), Junegrass (*Koeleria cristata*), Porcupine grass (*Stipa spartea*), smooth bromegrass (*Bromus inermis*), Sudan grass (*Andropogon sorghum*), seaside (*Agrostis palustris*) and velvet bent grasses (*Agrostis canina*), and Johnson grass (*Sorghum halepense*). Sampson and Malmsten (13) studied the effects of frequency of cutting on some of the western range grasses, and Biswell and Weaver (1) give the response of some prairie grasses to frequent clipping. Several of the papers cited present good literature reviews on the subject.

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[1]Joint contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal Article No. 347 (new series) of the Michigan Agricultural Experiment Station. Received for publication January 16, 1938.

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[3]Figures in parenthesis refer to "Literature Cited", p. 429.

MATERIALS AND METHODS

The present experiment was conducted in the greenhouse at the Michigan State College, East Lansing, Mich. Orchard grass (*Dactylis glomerata L.*), timothy (*Phleum pratense*), quack grass (*Agropyron repens*), Kentucky bluegrass (*Poa pratensis*), smooth brome grass (*Bromus inermis*), and a mixture of smooth brome grass and alfalfa were used. The plants were set out in 10-inch clay pots on October 9, 1936, using quartz sand instead of soil. For each of the five grass species used, 23 pots were each planted with eight vegetative segments collected from field plats, while four brome grass segments along with four alfalfa plants, about three months old, were set out in each of the pots containing the alfalfa and brome grass mixture. All plants were watered and supplied with a nutrient solution to secure the best growth under winter greenhouse conditions.

The nutrient solution contained the following concentrations and was applied once or twice per week:

Nutrient	Partial volume molecular concentration
KH_2PO_4	0.0045
$Ca(NO_3)_2 \cdot 4H_2O$	0.0090
$MgSO_4 \cdot 7H_2O$	0.0045

A trace of iron sulfate ($FeSO_4$) was added to the solution from time to time when the plants appeared to need iron.

The greenhouse temperature ranged between 70° and 80° F, except during the sunny days of May, when it occasionally went as high as 90° to 100°. The intensity of light and length of day in the greenhouse depended largely upon the weather conditions which were more or less cloudy during the winter, with about 50% of the days clear in the spring. No artificial light was used.

The plants were grown until March 29, at which time they had reached approximately the early bloom stage and the plants in three cultures of each set were washed out and green and dry weights determined for the tops and roots. These were used as the "initial checks".

The remaining cultures of orchard grass, timothy, quack grass, and brome grass were arranged in sets of five and were cut at 1 inch, 3 inches, and 6 inches above the sand, with one set of each species being left uncut to be washed out at the end of the trial and used as "final checks". Two sets of the alfalfa-brome grass cultures were cut at 1 inch and 6 inches, respectively, while another set was cut and gradually brought down to 2 inches in four cuttings and thereafter cut at 2 inches. One set was left as final checks. In the bluegrass series, the cutting treatments were ½ inch, 2 inches, 3 inches, and final checks.

The method of cutting consisted of raising all of the leaves of the plants and cutting them, along with the stems, back to the designated length.

Cutting began on March 30 and was repeated each week until May 26, 1937, when all plants were washed out, the tops separated from the roots, and green and dry weights taken. Green and dry weights were also determined each week for that portion of the tops removed.

EXPERIMENTAL RESULTS

YIELDS OF TOP GROWTH

Table 1 gives the average yields per culture in dry weight of top growth by the various species at the different heights of cutting.

The column labeled "total weight minus initial and last weights" gives the yields produced during all but the last week of the cutting period. During this period, orchard grass cultures cut at 1 inch, 3 inches, and 6 inches yielded 4.37, 16.65, and 23.09 grams, respectively. The yields of top growth produced by those orchard grass plants cut at 1 inch decreased steadily and quite rapidly from 2.3 grams during the first week of the period to 0 01 gram during the week ending May 19. The plants cut at 3 inches yielded 3.9 grams of dry weight during the first week, while those cut at 6 inches yielded 2.9 grams during the same period. Following a drop in production to 2.53 grams during the second week, the yields produced by the 3-inch cultures remained reasonably constant. The weekly yields of tops from the 6-inch cultures remained fairly constant at a level slightly above that of the 3-inch cultures.

The total yields of orchard grass tops were 22.51, 74 25, and 90.09 grams, respectively, by those plants cut at 1 inch, 3 inches, and 6 inches. The initial checks yielded 37 0 grams and the final checks 124.0 grams per culture. These results show that total yield of tops varied inversely with the severity of cutting treatment. The steady decline in the weekly yields of top growth by the cultures cut at 1 inch indicates that these plants were steadily using up their food reserves and did not have sufficient leaf surface remaining to manufacture the food necessary for a large growth. Cutting to 1 inch practically defoliates "high growing" grasses like orchard grass.

The difference between the initial weight of tops from the 1-inch cultures and that of the initial checks represents, approximately, the dry weight left in the lowest 1 inch of the tops. In the case of the 1-inch cultures, most of this original 1 inch was sloughed off and the yield of new growth was not enough to equal this loss.

Timothy behaved similarly to orchard grass, except that the yields of timothy were generally less than the corresponding yields of orchard grass. The total yields of timothy during all but the last week of the cutting period were 2.61, 8.83, and 15.33 grams, respectively, by the cultures cut at 1 inch, 3 inches, and 6 inches, showing that the amount of recovery growth varied inversely with the severity of cutting treatment.

The total yields of quack grass were about one-third to one-half as large as were those of the corresponding orchard grass cultures. The quack grass plants cut at 1 inch appeared to adapt themselves better to this severe treatment than did orchard grass and timothy. The average yield by the 1-inch cultures during the first week was 0.83 gram for quack grass and 2.3 grams for orchard grass; during the week ending May 19, quack grass yielded 0.23 gram and orchard grass, 0.01 gram. The weekly yields of quack grass from the 3-inch and the 6-inch cultures had about the same general trends as those of orchard grass receiving corresponding treatments.

The total dry weight of tops produced by the brome grass plants at 1 inch was 16.92 grams per culture, which was approximately equal to the dry matter in the initial check. The average total yield (47.21 grams) from the 6-inch cultures was approximately equal to that from the final check, which was 47.8 grams. These results indicate that

brome grass was less injured by the clipping treatments than were orchard grass and timothy because the 1-inch cultures of the latter yielded less dry weight of tops than the initial checks and the 6-inch cultures yielded less than the final checks.

It will be noted, however, that, in general, brome grass produced lower yields than did orchard grass or timothy receiving corresponding treatments. This may be partly accounted for by the fact that the entire set of brome grass cultures was located in a shadier part of the greenhouse than were the other grasses.

The brome grass cultures cut at 3 inches produced slightly more top growth during the first two weeks of the cutting period than did those cut at 6 inches. The yields by the plants cut at 3 inches were 2.46 and 1.51 grams, respectively, for the first and second weeks, compared with 2.26 and 1.21 grams from those cut at 6 inches. Beginning with the third week the 6-inch cultures yielded more than the 3-inch cultures.

The results obtained for the alfalfa-brome grass mixture indicate that brome grass was benefited by its association with alfalfa, especially when the plants were kept short. There were only one-half as many brome grass segments in each culture of the mixture as in each of the straight brome grass cultures. Nevertheless, the average yields per culture by the brome grass plants in the mixture cut at 1 inch were 0.33, 0.34, and 0 23 gram of dry weight, respectively, for the last three cuttings, compared with 0.16, 0 08, and 0.08 gram by the corresponding straight brome grass cultures.

The figures for bluegrass indicate that this grass could be maintained under the conditions of this experiment even when cut weekly at only ½ inch above the sand. The weekly yields from the ½-inch cultures declined at first but soon leveled out and remained approximately the same thereafter. The average total yield by the ½-inch cultures was 20.89 grams, which was 3.69 grams more than the dry matter harvested from the initial check. There were no essential differences between the weekly or the total yields of the bluegrass plants cut at 2 inches and those cut at 3 inches. The average total yield of the 2-inch cultures was 34.64 grams. while that of the 3-inch cultures was 36.25. The total yield during the cutting period, except for the last week, was 6.84 grams for the plants cut at 2 inches and 6.85 grams for those cut at 3 inches.

ROOTS AND RHIZOMES

The dry weight of roots in each culture and the average per culture for the various treatments are given in Table 2. Fig. 1 shows that the amount of roots produced by timothy decreased with increase in severity of cutting treatment. This behavior was also typical of the other grasses.

The average dry weight of roots in the orchard grass initial check cultures was 13.1 grams. By the end of the cutting period, the plants in four of the 1-inch cultures were dead, and the dry weight of roots in the other 1-inch culture was only 0.75 gram. The final check cultures averaged 30.8 grams of roots at the end of the same period.

TABLE 1.—*Average yield of tops per pot in grams of dry weight.*

Treatment	Initial weight Mar. 31	Cutting dates Apr. 7	Apr. 14	Apr. 21	Apr. 28	May 5	May 12	May 19	Washed out May 26	Total weight minus initial and last weights	Total
Orchard Grass											
Cut at 1 in.	17.9	2.3	1.14	0.54	0.29	0.06	0.03	0.01	0.24	4.37	22.51
Cut at 3 in.	13.4	3.9	2.53	2.22	1.91	1.79	2.25	2.05	44.2	16.65	74.25
Cut at 6 in.	5.3	2.9	3.06	3.66	3.56	3.51	3.76	2.64	61.7	23.09	90.09
Check (initial)	37.0	—	—	—	—	—	—	—	—	—	37.0
Check (final)	—	—	—	—	—	—	—	—	124.0	—	124.0
Timothy											
Cut at 1 in.	11.1	1.16	0.60	0.42	0.25	0.12	0.04	0.02	1.7	2.61	15.41
Cut at 3 in.	7.3	1.76	1.27	1.14	1.11	1.40	1.02	1.13	16.3	8.83	32.43
Cut at 6 in.	4.8	1.80	2.12	2.07	2.24	2.45	2.34	2.31	39.7	15.33	59.83
Check (initial)	23.7	—	—	—	—	—	—	—	—	—	23.7
Check (final)	—	—	—	—	—	—	—	—	76.8	—	76.8
Quack Grass											
Cut at 1 in.	8.3	0.83	0.68	0.62	0.47	0.30	0.25	0.23	1.1	3.38	12.78
Cut at 3 in.	6.6	1.24	0.90	0.78	0.75	0.78	0.83	0.75	10.0	6.03	22.63
Cut at 6 in.	4.0	0.95	0.96	0.98	0.92	1.11	1.06	1.08	21.1	7.06	32.16
Check (initial)	14.5	—	—	—	—	—	—	—	—	—	14.5
Check (final)	—	—	—	—	—	—	—	—	62.4	—	62.4
Brome Grass											
Cut at 1 in.	12.9	1.75	0.87	0.47	0.35	0.16	0.08	0.08	0.26	3.76	16.92
Cut at 3 in.	10.9	2.46	1.51	1.24	1.17	1.11	1.27	1.45	9.6	10.21	30.71
Cut at 6 in.	5.8	2.26	1.21	1.81	2.02	2.57	2.40	2.64	26.5	14.91	47.21
Check (initial)	16.7	—	—	—	—	—	—	—	—	—	16.7
Check (final)	—	—	—	—	—	—	—	—	47.8	—	47.8

					Bluegrass						
Cut at ½ in	15.1	1.08	0.72	0.54	0.54	0.44	0.48	0.49	1.5	4.29	20.89
Cut at 2 in	10.6	1.31	0.89	0.91	0.74	0.87	1.08	1.04	17.2	6.84	34.64
Cut at 3 in	7.7	1.26	0.70	0.78	0.85	1.12	1.08	1.06	21.7	6.85	36.25
Check (initial)	17.2		—					—	—	—	17.2
Check (final)	—		—	—	—			—	51.9	—	51.9
					Alfalfa and Brome Grass						
Cut at 1 in											
Alfalfa	9.9	0.82	1.02	0.93	0.52	0.53	0.45	0.37	2.9	4.64	17.44
Brome grass	9.2	0.33	0.52	0.40	0.27	0.33	0.34	0.23	0.7	2.42	12.32
Cut at 6 in											
Alfalfa	5.8	0.84	1.09	1.14	1.05	1.04	1.14	1.05	14.2	7.35	27.35
Brome grass	2.5	0.86	0.96	0.87	1.31	1.40	1.26	1.84	28.1	8.59	39.19
Cut at 2 in (gradually)											
Alfalfa	1.1	1.01	1.71	2.8	0.21	0.86	0.87	0.66	4.2	8.12	13.42
Brome grass	2.6	2.68	3.55	9.6	1.57	1.24	1.71	1.60	8.9	21.95	33.45
Check (initial)											
Alfalfa	3.8							—	—	—	3.8
Brome grass	7.1							—	—	—	7.1
Check (final)											
Alfalfa	—		—					—	18.2		18.2
Brome grass	—		—	—		—	—	—	47.8	—	47.8

TABLE 2.—*Dry weight of roots per pot, in grams.*

Treatment	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Av.
			Orchard Grass			
Check (initial)	11.5	11.0	16.8	—	—	13.1
Cut at 1 in	0.75	dead	dead	dead	dead	0.75
Cut at 3 in	9.4	9.2	9.9	9.8	10.4	9.7
Cut at 6 in	18.5	17.4	18.1	17.6	19.7	18.3
Check (final)	32.9	26.3	32.6	34.6	27.4	30.8
			Timothy			
Check (initial)	5.5	6.0	7.0	—	-	6.2
Cut at 1 in	0.16	0.17	0.94	0.82	dead	0.52
Cut at 3 in	3.53	5.34	4.0	5.0	2.9	4.15
Cut at 6 in	4.8	5.8	7.8	5.5	7.0	6.2
Check (final)	17.3	19.4	9.1	15.4	8.1	13.9
			Quack Grass			
Check (initial)	12.2	3.8	5.6	—		7.2
Cut at 1 in	2.4	0.6	0.6	1.8	1.3	1.3
Cut at 3 in	2.1	3.4	2.8	2.4	2.2	2.6
Cut at 6 in	2.6	6.5	4.6	3.5	5.1	4.5
Check (final)	7.1	5.3	4.3	3.4	3.9	8.9
			Brome Grass			
Check (initial)	10.7	13.5	11.0	—	—	11.7
Cut at 1 in	1.8	0.44	1.3	0.55	1.0	1.02
Cut at 3 in	21.8	11.3	11.7	10.6	11.3	13.3
Cut at 6 in	19.0	21.2	13.1	13.8	21.0	17.6
Check (final)	47.5	18.7	51.9	48.8	25.2	38.4
			Bluegrass			
Check (initial)	16.5	6.6	7.0	-	—	10.0
Cut at ½ in	4.1	5.3	4.2	5.1	3.3	4.4
Cut at 2 in	8.2	8.7	3.6	6.0	4.7	6.2
Cut at 3 in	4.5	8.4	6.7	5.4	6.2	6.2
Check (final)	8.5	8.9	10.0	5.9	5.6	7.8
			Alfalfa (Brome)*			
Check (initial)	7.5	7.0	3.5	—	—	—
Cut at 1 in	4.8	2.9	4.4	3.2	3.6	3.8
Cut at 6 in	16.1	9.5	7.6	9.9	12.6	11.1
Cut gradually to 2 in	6.8	4.9	3.5	6.7	5.4	5.5
Check (final)	25.4	11.3	5.9	13.2	19.8	15.1
			Brome (Alfalfa)†			
Check (initial)	12.8	10.0	15.8	—	—	12.9
Cut at 1 in	5.8	2.4	3.9	1.6	4.3	3.6
Cut at 6 in	9.1	15.0	12.2	8.3	7.5	10.4
Cut gradually to 2 in	11.0	15.3	8.8	11.3	11.7	11.6
Check (final)	24.6	36.4	53.1	36.6	42.9	38.7

*Alfalfa roots from the alfalfa brome mixture.
†Brome grass roots from the alfalfa brome mixture.

These results indicate that those plants cut at 1 inch used up practically all of their root reserves in producing new top growth. They were kept so nearly defoliated that they never had an opportunity to manufacture and store new supplies of reserve food. The plants cut

at 3 inches also showed a net loss, while those cut at 6 inches increased the weight of dry matter in their roots but not nearly as much as did the final checks.

In general, the timothy plants yielded considerably less dry weight of roots than did the corresponding orchard grass plants. The timothy cultures cut at 1 inch behaved in about the same manner as orchard

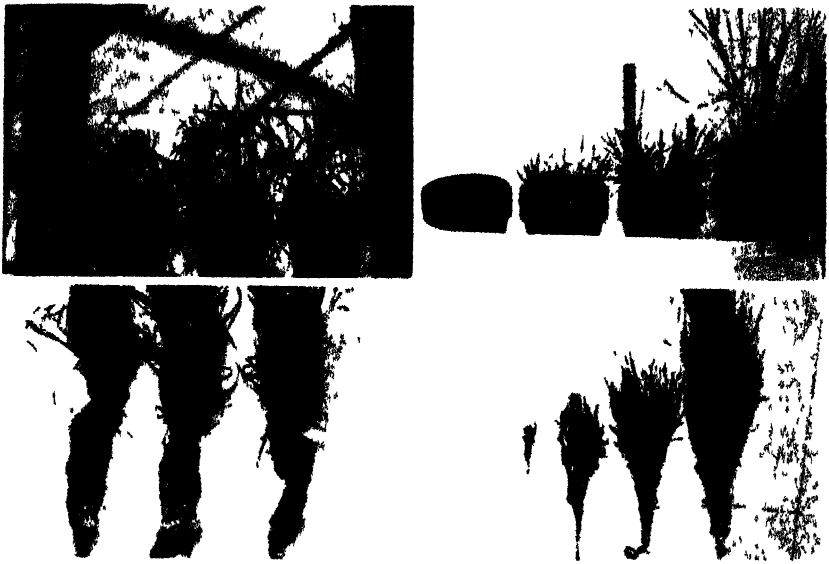

FIG. 1. Timothy. *Upper left*, the initial checks taken at the beginning of the cutting period. *Lower left*, the initial checks after they had been removed from the pots and washed free of sand. Taken on the same day as the upper picture. Note the uniformity in the amount of roots per culture. *Upper right*, picture taken at the end of the cutting period. Reading from left to right, cultures cut at 1 inch, 3 inches, 6 inches and final check. *Lower right*, picture of the same plants as above after they had been removed from the pots and washed free of sand. Note how the amount of roots per culture increases with decrease in severity of cutting treatment. The amount of roots in the 6-inch culture was approximately the same as in the initial checks but the latter were closer to the camera.

grass, except that in only one culture were all of the plants dead. The roots of the other four 1-inch cultures averaged only 0.52 gram per culture. The 3-inch cultures had an average of 4.15 grams of roots and those cultures cut at 6 inches averaged 6.2 grams, which was exactly the same as the initial check and 7.7 grams less than the final check.

Quack grass, smooth brome grass and Kentucky bluegrass have growth habits somewhat different from those of orchard grass and timothy. All three of the former produce rhizomes in addition to roots, when environmental conditions are favorable for the production of rhizomes. The dry weight of roots (Table 2) indicates that these three grasses were more adapted to close clipping than were orchard grass

and timothy, because the amounts of roots produced by the 1-inch quack grass and brome grass cultures and by the ½-inch bluegrass cultures were greater than those produced by the orchard grass and timothy cultures cut at 1 inch.

The quack grass plants cut at 1 inch, 3 inches, and 6 inches possessed roots that averaged 1.3, 2.6 and 4.5 grams per culture, respectively, at the end of the cutting period. The initial checks averaged 7.2 grams and the final checks 8.9 grams. All treatments resulted in some loss in root weight, except the final check which added only 1 7 grams.

The dry weights of rhizomes are given in Table 3. The quack grass cultures averaged 3.60, 5.30, 7.08, 15.60, and 49.70 grams, respectively, for the initial check, 1-inch clipping, 3-inch clipping, 6-inch clipping, and final check. The quack grass under all treatments showed some increase in rhizomes over those produced by the initial check. These results, together with the fact that all of the clipped cultures produced less roots than the initial check, indicate that quack grass may have produced rhizomes at the expense of its roots.

TABLE 3.—*Dry weight of rhizomes per pot in grams*

Treatment	Pot 1	Pot 2	Pot 3	Pot 4	Pot 5	Av
			Quack Grass			
Check (initial)	3 8	2 0	5 0		—	3.60
Cut at 1 in	3 0	4.5	8.5	6 0	4 5	5.30
Cut at 3 in	7.0	9 5	6.5	6.4	6.0	7 08
Cut at 6 in	15 5	17.0	14.0	17.0	14.5	15.60
Check (final)	54.5	47.5	48.0	43.0	55 5	49.70
			Brome Grass			
Cut at 6 in	--	—	—	1.5	0.6	1 05
Check (final)	2 0	---	0 5	1 0	3 5	1.75
			Bluegrass			
Check (initial)	2.3	2.5	2 0			2 27
Cut at ½ in	4.0	1.6	2.5	1.1	2.0	2.24
Cut at 2 in	8.5	4.5	3.5	4.0	3.6	4.82
Cut at 3 in	6.5	6.0	5.5	8 5	6.5	6.60
Check (final)	33.0	9.0	10.6	7.0	12.5	14.42
			Alfalfa (Brome)			
Cut at 1 in	0.2	0.1	0.5	—	-	0.3
Cut at 6 in	0.2	0.5	0.4	--	—	0.4
Cut gradually to 2 in	0.8	0.4	0.8	—	0.5	0.6
Check (final)	2.5	8.0	6.0	5.5	9.0	6.2

Brome grass produced fewer rhizomes than quack grass and appeared less resistant to close clipping. None of the clipped brome grass plants, except those in pots Nos. 4 and 5 of the 6-inch cultures, produced rhizomes. The rhizomes of these two cultures weighed 1.5 and 0.6 grams, respectively. There were practically no rhizomes on the initial check brome grass plants, and only four of the final check cultures possessed rhizomes. The average dry weight of rhizomes on these four cultures was 1.75 grams.

The average dry weights of brome grass roots per culture (Table 2) were 1.02, 13.3, and 17.6 grams, respectively, for the 1-inch, 3-inch and 6-inch cultures, compared with 11.7 and 38.4 grams, respectively, for the initial and final checks. Table 2 shows that even those plants cut at 3 inches produced an increase in dry weight of roots over the initial checks and that all the of 1-inch cultures contained some living plants at the end of the cutting period. These results indicate that brome grass was more adapted to close clipping than were orchard grass and timothy.

Where brome grass was grown in pots with alfalfa, the dry weights of the brome grass roots (Table 2) averaged 12.9, 3.6, 10.4, 11.6, and 38.7 grams per culture, respectively, for the initial checks, the plants cut at 1 inch, those cut at 6 inches, those cut gradually to 2 inches, and the final checks.

Although there were no rhizomes on the initial checks of brome grass associated with alfalfa (Table 3), at least three cultures in each treatment contained rhizomes at the end of the cutting period. The final checks averaged 6.2 grams of rhizomes per culture compared with 1.75 grams where brome grass was grown alone. When one considers that there were only one-half as many original grass plants in each culture of the alfalfa and brome grass mixture as in the straight brome grass, these results definitely support the contention that the brome grass was benefited by its association with alfalfa

Bluegrass behaved more nearly like quack grass than did brome grass. Because bluegrass produces considerable photosynthetic area close to the ground, it was cut at ½ inch, 2 inches, and 3 inches instead of 1 inch, 3 inches, and 6 inches The extremely high weight of roots (Table 2) in pot No. 1 of the initial bluegrass checks raises the average initial check weight higher than it would otherwise be. Disregarding this culture, the average dry weight of roots per culture was 6.8 grams for the initial checks, 4.4, 6.2, and 6.2 grams, respectively, for the plants cut at ½ inch, 2 inches, and 3 inches, and 7.8 grams for the final checks. The data in Table 2 indicate that there was practically no difference between cutting bluegrass at 2 inches and cutting it at 3 inches insofar as root development was concerned, and also that bluegrass was not critically injured by cutting it as close as ½ inch above the sand.

The data for the average dry weight per culture of bluegrass rhizomes (Table 3) are 2.27 grams for the initial checks, 2.24, 4.82, and 6.60 grams, respectively, for the ½-inch, 2-inch, and 3-inch cultures, and 14.42 grams for the final checks. These results do indicate some difference, which may not be important, between the plants cut at 2 inches and those cut at 3 inches. The plants cut at ½ inch just about "held their own" insofar as rhizomes were concerned, while the final checks yielded considerably more dry weight of rhizomes than did any of the clipped plants.

GENERAL DISCUSSION

The foregoing experimental results are intended to supplement the information already available regarding the effects of clipping upon

the behavior of perennial grasses, particularly upon the yields of tops and underground parts.

All of the grasses used in the experiment are of economic importance in Michigan. Quack grass is considered a noxious weed, and information regarding its response to various cutting treatments should aid in developing methods for its control. Orchard grass, timothy, smooth brome grass, and Kentucky bluegrass are used, to a greater or less extent, as pasture grasses in Michigan and other states. While cutting does not exactly simulate grazing, it does give some indication as to how grasses may respond to different intensities of grazing.

Grasses require chlorophyll-bearing tissue in order to manufacture carbohydrates. After all of the green leaves have been removed from a grass plant, new growth is initiated at the expense of carbohydrates previously stored in some remaining part of the plant. The new growth begins to manufacture more carbohydrates, and, if more carbohydrates are manufactured than are required immediately for growth or other consumption, the excess is stored for future use. When the interval between successive removals of the photosynthetic tissue is so short that the plant does not have time to replace the stored carbohydrates that it used in producing the new growth, the reserve supply will gradually become depleted to a point where it will be a limiting factor in the amount of new growth made before the next cutting. From this point on the reserve supply of carbohydrates continues to decrease, and the amount of new growth produced between successive cuttings gets less and less until there are not enough reserve carbohydrates to initiate any new growth and death of the plant results.

If the grass plants are cut high enough so that some green leaf tissue remains, a smaller amount of the reserve carbohydrates may be used in producing the new growth. If the plants were cut still higher, they might not use any of the reserves in producing new growth and might even keep on storing some carbohydrates.

Bluegrass withstood close cutting better than the other grasses because, under the conditions of the present experiment, it produced the most green leaves below a height of 1 inch. In other words, it produced more photosynthetic tissue close to the sand than did any of the other grasses

At the beginning of the cutting period the grass plants were relatively high in carbohydrates. (Nitrogen had been withheld from the plants for a few weeks in order to allow them time to store some carbohydrates). Cutting some of the grasses (orchard grass, quack grass, and brome grass) at 3 inches resulted in more new growth being produced during the first week of the cutting period than cutting them at 6 inches. The removal of more carbohydrates and carbohydrate-manufacturing tissue from the plants cut at 3 inches resulted in them having less carbohydrates in relation to the nitrogen present than those cut at 6 inches and may have made the relationship of carbohydrates to nitrogen in the plants cut at 3 inches more favorable for vegetative extension. After some of the reserve carbohydrates had been used, the proportion of carbohydrates to nitrogen in the plants cut at 3 inches was probably too low to produce the most favorable

conditions for vegetative extension. This resulted in the 3-inch cultures making less growth than the 6-inch cultures after the first or second week. The plants cut at 3 inches depleted their carbohydrate reserves more rapidly than those cut at 6 inches during the first week because they made more growth and also had less leaf tissue with which to manufacture carbohydrates. Consequently, since they used more carbohydrates and manufactured less, the plants cut at 3 inches depleted their reserves faster than those cut at 6 inches.

In the case of the plants cut at 1 inch, so much of the carbohydrates was removed by the first clipping that the amount of carbohydrates left in the plants in relation to the nitrogen present was probably too small from the beginning of the cutting period to produce the most favorable conditions for vegetative extension. Perhaps the plants could have been cut at some height above or below 3 inches at which they would have made more growth during the first week than they did when cut at 3 inches.

SUMMARY AND CONCLUSIONS

1. Orchard grass, timothy, smooth brome grass, quack grass, Kentucky bluegrass, and a mixture of smooth brome grass and alfalfa were grown in 10-inch clay pots in the greenhouse and cut weekly at three different heights.

2. There were differences between the various species in the amount of injury incurred by continuous close clipping. In this respect they rated in the following order, beginning with the one least injured: Kentucky bluegrass, quack grass, smooth brome grass, with timothy and orchard grass being about equal.

3. In nearly every case the greatest total yield of top growth was obtained from those plants that were allowed to go unclipped. In general, the shorter a given grass was cut, the less top growth it produced.

4. The greatest yields of underground parts (roots and rhizomes) were also obtained from the uncut plants. The yields of underground parts decreased with increase in severity of cutting treatment.

5. Smooth brome grass did better when grown in a mixture with alfalfa than when grown alone.

LITERATURE CITED

1. Biswell, H. H., and Weaver, J. E. Effects of frequent clipping on the development of roots and tops in the prairie sod. Ecology, 14:368-390. 1933.
2. Dexter, S. T. Response of quack grass to defoliation and fertilization. Plant Physiol., 11:843-851. 1936.
3. Graber, L. F. Competitive efficiency and productivity of bluegrass (*Poa pratensis L.*) with partial defoliations at two levels of cutting. Jour Amer. Soc. Agron., 25:328-333. 1933.
4. ———. Food reserves in relation to other factors limiting the growth of grass. Plant Physiol., 6:43-72. 1931.
5. ———, Nelson, N. T. Leukel, W. A., and Albert, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wis. Agr. Exp. Sta. Res. Bul. 80. 1927.
6. Harrison, C. M. Effect of cutting and fertilizer applications on grass development. Plant Physiol., 6:669-684. 1931.

7. ————. Responses of Kentucky bluegrass to variations in temperature, light, cutting, and fertilizing. Plant Physiol., 9:83–106. 1934.
8. LEUKEL, W. A., and COLEMAN, J. M. Growth behavior and maintenance of organic foods in Bahai grass. Fla. Agr. Exp. Sta. Bul. 219. 1930.
9. ————, CAMP, J. P., and COLEMAN, J. M. Effect of frequent cutting and nitrate fertilization on the growth behavior and relative composition of pasture grasses. Fla. Agr. Exp. Sta. Bul. 269. 1934.
10. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation and stage and height of cutting on yield and composition of Kentucky bluegrass (*Poa pratensis L.*).
11. PIERRE, W. H., and BERTRAM, F. E. Kudzu production with special reference to influence of frequency of cutting on yields and formation of root reserves. Jour. Amer. Soc. Agron., 21:1079 1101. 1929.
12. ROBERTSON, JOSEPH H. Effect of frequent clipping on the development of certain grass seedlings. Plant Physiol., 8:425 447. 1933.
13. SAMPSON, A. W., and MALMSTEN, H. E. Grazing periods and forage production on the national forests. U. S. D. A. Bul. 1405. 1926.
14. SPRAGUE, HOWARD B. Root development of perennial grasses and its relation to soil conditions. Soil Science, 36:189–209. 1933.
15. STURKIE, D. G. The influence of various top-cutting treatments on rootstalks of Johnson grass (*Sorghum halepense*). Jour. Amer. Soc. Agron., 22:82-93. 1930.

A STUDY OF A CORRELATION OF CHEMICALLY AVAILABLE PHOSPHORUS WITH CROP YIELDS[1]

A. C. RICHER AND J. W. WHITE[2]

ONE of the most widely accepted chemical methods for the determination of available phosphorus is that proposed by Truog (8).[3] It has been shown by several workers (1, 2, 5, 6, 7) that the Truog method compared well with other methods, and in general, gave good agreement with field results. However, the method has not been applied to phosphate field plats, except for the work of Snider (7).

The purpose of this study, therefore, was to determine the degree of correlation of available phosphorus as determined by the Truog method with crop yields of two field plat fertilizer experiments. These include comparisons of plats receiving various carriers and amounts of phosphate fertilizers.

The first series of plats considered were those of one tier of a phosphate field plat experiment which compares the various sources of phosphorus, such as, superphosphate, rock phosphate, steamed bone meal, and basic slag. This experiment was begun in 1916 and the relative efficiency of the various sources as measured by crop yields was reported by Noll, Irvin, and Gardner in 1935 (4).

One tier of the Jordan soil fertility plats constituted the second series of plats considered. This experiment was planned to test comparative effects of fertilizers without any special reference to phosphorus. This soil fertility experiment, the oldest extensive field plat experiment in America, was laid out in 1881, and the results for 50 years were summarized in 1931 (3).

Both of these experiments are located at the Pennsylvania Agricultural Experiment Station. The soil is Hagerstown silt loam, a residual soil of limestone origin. The rotation is corn, oats, wheat, and hay (mixed clover and timothy) one year each The fertilizers are applied to corn and wheat only.

EXPERIMENTAL

Samples were taken from tier 2 of the phosphate field experiment and from tier 4 of the Jordan soil fertility plats. The samples were taken with a soil auger to a depth of 7 inches. The soils were prepared for analysis by air drying and passing through a 20-mesh screen.

The available phosphorus was determined by the Truog method (8) which consists of extracting the soils with 0.002 N sulfuric acid, buffered at pH 3.0, and estimating the phosphorus in the extract colorimetrically.

The pH value was determined potentiometrically, the voltage reading being

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[3]Figures in parenthesis refer to "Literature Cited", p. 437.

taken immediately after the addition of quinhydrone to a 1 to 1 mixture of soil and distilled water.

All results are the average of at least two determinations.

DISCUSSION OF RESULTS

PHOSPHATE FERTILIZER PLATS

Since lime has been applied on all plats to meet the lime requirement, soil reaction is not a factor. However, the pH of the soil is indicated, but, as can be seen, the pH values do not vary much from pH 6.5.

For purposes of comparison, the plats pertaining to this study were grouped into Tables 1, 2, and 3. The total crop yields are expressed in pounds per acre and are the sum of the yields for one rotation preceding the time of sampling. The data presented in Tables 1 and 2 show that the crop yields correlate much better with the amounts of superphosphate added than with the available phosphorus of the soil. There is only a small increase in the available phosphorus with increasing amounts of superphosphate added (with one exception) whether the superphosphate is added with manure or commercial fertilizers. Although manure increased the crop yields considerably, there was a decrease of available phosphorus extracted

TABLE 1.—*Comparison of crop yields and available phosphorus on plats treated with rock phosphate and superphosphate when applied with uniform amounts of nitrogen and potash, phosphate experiment plats.**

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation in lbs. per 4 acres	Relative crop yield	Lbs. of available phosphorus per acre
10	None	6.68	8,668	100	22.4
3	150 superphosphate	6.88	12,166	140	27.2
4	300 superphosphate	6.66	13,378	154	21.6
7	450 superphosphate	6.69	15,296	176	28.8
9	600 superphosphate	6.74	15,282	176	46.4
14	150 rock phosphate	6.56	10,242	118	72.0
15	300 rock phosphate	6.47	11,097	128	152.0
17	450 rock phosphate	6.52	12,421	144	240.0

*Also 130 lbs. of nitrate of soda and 100 lbs. muriate of potash.

TABLE 2.—*Comparison of crop yields and available phosphorus of plats treated with rock phosphate and superphosphate when applied with 6 tons of manure, phosphate experiment plats.*

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation, lbs. per 4 acres	Relative crop yield	Lbs. of available phosphorus per acre
22	None	6.58	13,785	100	16.8
23	150 superphosphate	6.39	15,293	111	20.8
24	300 superphosphate	6.61	15,571	113	20.8
25	450 superphosphate	6.30	16,018	116	25.8
29	300 rock phosphate	6.52	15,834	115	176.0
30	450 rock phosphate	6.40	15,102	110	264.0
32	600 rock phosphate	6.29	16,980	123	316.0

(comparing Tables 1 and 2). It is apparent that the phosphorus of superphosphate, in excess of the amount taken up by the plants, is practically all fixed by the soil and is not dissolved by Truog's reagent.

The chemically available phosphorus was very high on the rock phosphate-treated plats. The increase in available phosphorus extracted was directly proportional to the amount of rock phosphate applied. The yields also increased with increasing amounts of rock phosphate,[4] but the increase was gradual and not proportional to the available phosphorus extracted. The addition of manure to rock phosphate increased the amount of available phosphorus extracted over the rock phosphate treatments alone. Although the available phosphorus as measured by the Truog method on the rock phosphate treatments was much greater than on the superphosphate treatments, the superphosphate was a much better source of phosphorus as evidenced by the higher crop yields produced.

This leads to the conclusion that all of the phosphorus extracted from the rock phosphate treatments is not available to the plants, although according to Truog's method it is termed readily available.

Table 3 compares the effects of various carriers of phosphorus when applied at the rate of 48 pounds of P_2O_5 per acre. The basic slag and superphosphate are highest and about equal in yield, with bone meal next, and rock phosphate as the poorest source of phosphorus. However, the chemically available phosphorus is greatest on the rock phosphate-treated plat. It is important to note also that the bone meal treatments behave like rock phosphate treatments but to a lesser degree, insofar as chemically available phosphorus is concerned.

TABLE 3.—*Comparison of crop yields and available phosphorus of plats treated with different carriers of phosphoric acid when applied with uniform amounts of nitrogen and potash, phosphate experiment plats.**

Plat No.	Phosphate fertilizer	pH	Total crop yields per rotation, lbs. per 4 acres	Relative crop yield	Lbs of available phosphorus per acre
10	None	6.68	8,668	100	22.4
4	300 superphosphate†	6 66	13,378	154	21 6
12	200 bone meal†	6 43	11,888	129	43.2
13	300 basic slag†	6.71	13,306	154	28.0
14	150 rock phosphate†	6.56	10,242	118	72.0

*Also 130 lbs of nitrate of soda and 100 lbs. muriate of potash
†Each treatment = 48 lbs P_2O_5 per acre

Where either rock phosphate or bone meal has been applied Truog's extracting reagent dissolves considerable more phosphorus than is easily available to the plant. It was found that if rock phosphate was extracted alone or after being mixed with soil in amounts in which the rock phosphate is agriculturally applied, all of the rock phosphate was dissolved by Truog's reagent and therefore was termed readily

[4]The rock phosphate used until the spring application in 1928 was that which had been ground for making superphosphate. Thereafter, a more finely ground phosphate, intended for direct use, has been applied. There is no evidence that the more finely ground rock phosphate is more efficient (4).

available phosphorus. The phosphorus of rock phosphate is not as available to crops as that contained in superphosphate, as shown by Tables 1, 2, and 3. However, the chemically available phosphorus of the rock phosphate treatments is many times greater than on any other treatment. Snider (7) also noted the same behavior of rock phosphate-treated soils. It must be concluded therefore that rock phosphate when placed in neutral soils, such as in this experiment, is only slightly soluble in soil solution. The small amount that does dissolve is fixed either in a difficultly available form as basic ferric and aluminum phosphates, or in a moderately available form as the various calcium phosphates. A considerable portion of the rock phosphate, however, does not dissolve and remains as such in the soil, much the same as any inert material.

The extracting reagent, 0.002 N H_2SO_4 at pH 3, undoubtedly dissolves all phosphates combined with calcium, but it is apparent from the crop yields that all calcium phosphate compounds, such as in rock phosphate or bone meal, are not "readily available" to the plant.

The results indicate, therefore, that where rock phosphate has been applied, Truog's method is not applicable unless the investigator takes into consideration the fact that the results in terms of available phosphorus will be unusually high. Direct comparisons between rock phosphate treatments and treatments of other carriers of phosphorus will lead to erroneous conclusions concerning the available phosphorus of the soils in question.

The same precautions must be observed when considering chemically available phosphorus of bone meal treatments. The results in terms of available phosphorus, although too high, are not nearly as high as with rock phosphate treatments. More data is presented below on bone meal-treated plats.

JORDAN SOIL FERTILITY PLATS

The available phosphorus and yields of one tier of the Jordan soil fertility plats is shown in Table 4. It can be seen that, in general, there is an excellent correlation between the available phosphorus and the crop yields. The two bone meal plats, Nos. 12 and 35, are outstanding in that the same results are found as were noted with the rock phosphate treatments of the first series of plats discussed, namely, that the available phosphorus is considerably higher than is evidenced by crop yields. Apparently, bone meal contains phosphorus which is not readily available for plant use and yet is termed readily available by virtue of the fact that it is soluble in Truog's reagent.

The manure plats, Nos. 16, 18, and 20, on the other hand, gave yields which, as would be expected, were much higher than the available phosphorus would indicate.

In general, however, the correlation between yields and available phosphorus was remarkable. The coefficient of correlation on all 36 plats was .55. If the two bone meal plats, Nos. 12 and 35, were omitted from the calculation, the coefficient of correlation rose to .82. Then, if in addition to the two bone meal plats, the three manure plats,

Nos. 16, 18, and 20, were omitted from the calculation, the coefficient of correlation was .91.

TABLE 4.—*Comparison of crop yield and available phosphorus of tier 4 of the Jordan soil fertility plats.*

Plat No.	Treatment*	pH	Total crop yield per rotation, lbs. per 4 acres	Lbs. of available phosphorus per acre
1	No treatment	7.50	6,682	16.8
2	N, 24 lbs. N (D. B.)	6.91	7,169	18.4
3	P	6.98	10,287	41.6
4	K	6.98	6,549	14.4
5	NP, 24 lbs. N (D. B.)	6.56	11,811	38.4
6	NK, 24 lbs. N (D. B.)	6.91	7,470	18.4
7	PK	6.49	15,565	33.6
8	No treatment	7.01	7,447	17.6
9	NPK, 24 lbs. N (D. B.)	6.26	15,802	37.6
10	NPK, 48 lbs. N (D. B.)	6.05	15,815	34.4
11	NPK, 72 lbs. N (D. B.)	6.54	16,266	39.2
12	NPK, 30 lbs. N (D. B.)	7.35	13,382	98.0
13	Corn 6 tons manure + P, wheat NPK†	7.79	11,843	28.8
14	No treatment	7.89	5,980	17.6
15	PK unlimed	6.88	13,066	30.4
16	6 tons manure	7.27	16,502	19.2
17	NPK, 24 lbs. N (D. B.).	6.81	14,820	28.8
18	8 tons manure	7.15	17,126	24.0
19	NPK, 48 lbs. N (D. B.)	6.90	15,613	32.0
20	10 tons manure	7.07	18,761	24.0
21	NPK, 72 lbs. N. (D. B.)	6.61	16,883	32.0
22	6 tons manure + 30 P_2O_5	8.25	18,506	44.8
23	CaO up to 1922; no treatment since	8.38	9,335	26.4
24	No treatment	7.07	8,220	16.0
25	PK unlimed	5.47	14,453	40.8
26	NPK, 24 lbs. N ($NaNO_3$)	6.49	18,056	41.6
27	NPK, 48 lbs. N ($NaNO_3$)	6.46	17,977	38.4
28	NPK, 72 lbs. N ($NaNO_3$)	6.46	18,842	47.2
29	PK	6.44	17,322	46.4
30	NPK, 24 lbs. N $(NH_4)_2SO_4$	6.44	20,165	48.0
31	NPK, 48 lbs. N $(NH_4)_2SO_4$	6.61	22,761	58.0
32	NPK, 72 lbs. N $(NH_4)_2SO_4$	6.58	22,204	46.4
33	$CaSO_4$ up to 1922; no treatment since	7.12	9,765	20.0
34	$CaCO_3$ up to 1922; no treatment since	8.38	11,006	28.0
35	NPK, 30 lbs. N (D. B.)	6.78	18,447	60.0
36	No treatment	7.78	12,224	28.0

*D. B. = Dried blood; P = 48 lbs. P_2O_5 per acre in superphosphate; K = 100 lbs K_2O per acre in muriate of potash.

On plats 12 and 35, P is derived from bone meal. No lime applied from 1881 to 1921, except on plats 22, 23, and 34. Lime was applied to all plats in 1922 and 1932, except plat 25. Dissolved bone black was the source of P, except on plats 12 and 35, up to 1917; since then superphosphate has been substituted for it. All treatments are applied to corn and wheat.

†To corn, 6 tons manure + 30 lbs. P_2O_5; to wheat, 10 lbs. N ($NaNO_3$) + 60 lbs. P_2O_5 + 50 lbs. K_2O.

The correlation is even more impressive when it is realized that the nitrogen and potash are not constants on all the plats. Nitrogen in particular is applied at three different rates and in three different forms.

Because of the high degree of correlation of yields with available phosphorus, it can be concluded that phosphorus is one of the primary limiting factors for crop growth on this particular soil. Phos-

phorus, however, is not the only limiting factor, since the application of phosphorus alone (plat 3) is not sufficient to obtain high crop yields.

The lack of correlation on the phosphate fertilizer plats was probably due to two reasons. First, various sources of phosphorus were applied and the readily available phosphorus as determined by the Truog method varied with the phosphorus carrier applied. Second, these plats were begun 35 years later than the Jordan soil fertility plats and so the older plats have had a much longer time to approach an equilibrium with respect to phosphorus applied and phosphorus available.

SUMMARY AND CONCLUSIONS

This study included a correlation of the readily available phosphorus as measured by the Truog method with crop yields of two field plat fertilizer experiments. The first was a phosphate fertilizer experiment and the second a general fertilizer experiment.

The results indicate that when readily available phosphorus as determined by the Truog method is to be used as one index of fertility, it is of the utmost importance to know the history of the soils in question, particularly as to the kind of phosphorus fertilizers that have been applied. The best comparative results on any particular soil will be obtained when the same carrier of phosphorus has been applied to all the soils studied. Erroneous conclusions will be drawn if various phosphorus fertilizers were used on the soils examined, unless the investigator takes into consideration the limitations of the method in the interpretation of the results.

As a result of these studies, the following conclusions seem justified:

1. There is no correlation of available phosphorus with crop yields in the comparison of plats receiving various carriers of phosphorus, such as superphosphate, rock phosphate, basic slag, and bone meal.

2. Plats receiving double or triple amounts of superphosphate showed only small increases in the available phosphorus extracted.

3. The available phosphorus of rock phosphate-treated plats was directly proportional to the amount applied, but it was many times higher than that of plats receiving superphosphate in equivalent amounts.

4. Truog's reagent dissolved considerably more phosphorus from soils treated with rock phosphate than is easily available to the plant as measured by crop yields. The same condition occurred with bone meal treatments but to a lesser degree.

5. The available phosphorus showed an excellent correlation with crop yields on one tier of the Jordan soil fertility plats. The only exceptions were the few plats receiving either bone meal or manure. If these plats were omitted in the calculation, the coefficient of correlation was .91. This high correlation is due to the fact that the phosphorus carrier was always the same, namely, superphosphate, and that these plats are approaching a phosphorus equilibrium after more than 50 years of existence.

LITERATURE CITED

1. ENGBERG, C. A., and SPURWAY, C. H. A comparison of field methods for determining the available phosphorus of soils. Jour. Amer. Soc. Agron., 25:354-360. 1933.
2. HOCKENSMITH, R. D., GARDNER, R., and GOODWIN, J. Comparison of methods for estimating available phosphorus in alkaline calcareous soils. Colo. Agr. Exp. Sta. Tech. Bul. 2. 1933.
3. NOLL, C. F., GARDNER, F. D., and IRVIN, C. J. Fiftieth anniversary of general fertilizer tests. Penn. Agr. Exp. Sta. Bul. 264. 1931.
4. ———, IRVIN, C. J., and GARDNER, F. D. Field experiments with phosphates. Penn. Agr. Exp. Sta. Bul. 315. 1935.
5. ROST, C. O., and PICKNEY, R. N. Colorimetric methods for the determination of readily available phosphorus. Jour. Amer. Soc. Agron., 24:377-395. 1932.
6. SMITH, F. B., BROWN, P. E., and SCHLOTS, F. E. A comparison of the Niklas and Truog methods for determining available phosphorus in soils. Jour. Amer. Soc. Agron., 24:452-460. 1932.
7. SNIDER, H. J. A comparison of methods for determining the available phosphorus in soils. Jour. Amer. Soc. Agron., 24:680-686. 1932.
8. TRUOG, E. The determination of readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874-882. 1930.

POTASH AVAILABILITY STUDIES IN PENNSYLVANIA ORCHARD SOILS[1]

E. C. DUNKLE, F. G. MERKLE, AND R. D. ANTHONY[2]

DURING the season of 1937 Dunbar and Anthony (2)[3] noted what appeared to be definite cases of potash deficiency in certain peach orchards. This deficiency was manifested by the color and curling of the leaf and was apparently overcome quite rapidly by applying soluble potassium salts around affected trees. It seemed possible that, since many growers of both apples and peaches use little or no potash in their fertilizer, the lack of this element might be beginning to show deficiency symptoms and that other orchards showing no visible symptoms at present might be on the verge of a deficiency. With deep-rooted perennials like apples and peaches, a deficiency could exist without noticeably lowering the yield or wood growth and still gradually influence the vigor, longevity, and finally the yield.

It is realized that field comparisons with and without potash provide the best answer to the question and that such comparisons should be made over a considerable period of years to produce valid conclusions. Nevertheless, pending the initiation of such trials and to provide a better basis upon which to make field trials, the following soil studies were planned. These are in a sense preliminary and part of a more comprehensive program of study on the subject of soil potash availability.

The phases of study reported in this paper are as follows:

1. The relative amounts of exchangeable potassium in surface vs. subsoils in Pennsylvania orchards.
2. The relation between the amount of organic matter in orchard soils and exchangeable potassium.
3. A comparison between different soil series in regard to exchangeable potassium.
4. A comparison of rapid tests for exchangeable soil potassium with a routine procedure.
5. Foliage analysis as indicative of deficiency and response.

Forty-seven commercial orchards representing the major fruit sections of the state (Fig. 1) were examined and soil samples taken. Field notes included the type of soil, condition of tree, kind and amount of fertilizer, and lime and manure used, together with the cover cropping or other cultural system. Orchards were selected having high and low organic contents. Some received potash fertilizers, others none. In addition to samples taken in 1938 there were available the orchard soil samples taken by Shaulis and Merkle (9) in their study of the effects of orchard management practices upon the

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[3]Figures in parenthesis refer to "Literature Cited", p. 457.

organic content and porosity. Valuable advice in the choice of sites was received from C. O. Dunbar, N. J. Shaulis, John Reuf, and others.

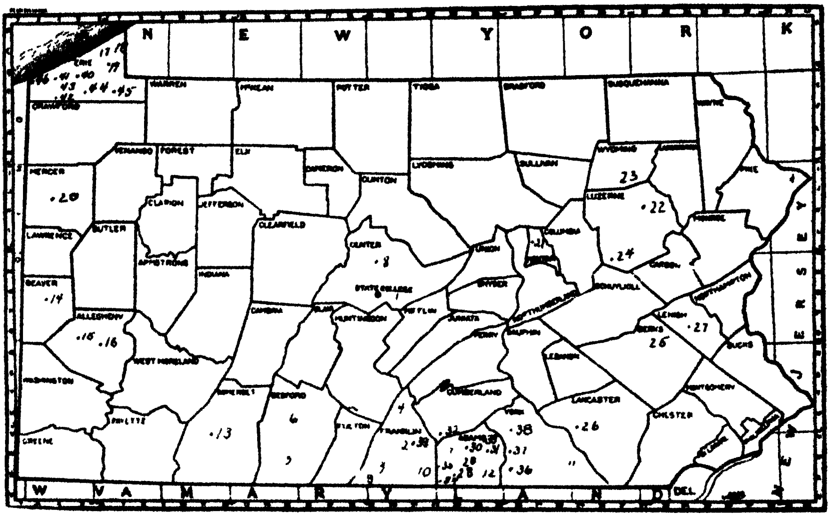

FIG. 1.—Distribution of sites.

RELATIVE AMOUNTS OF EXCHANGEABLE POTASSIUM IN SURFACE VS SUBSOILS

Due to the greater clay content of the subsoils of practically all podzolic soils, more total potassium is found in the lower layers. However, organic matter in the surface soil may be expected to maintain a higher level of exchangeable potassium in the surface. This is partly the result of biological activity and partly physico-chemical. The surface soils, taken to the depth to which plowing was customary, were compared with the subsoils taken in a zone 12 inches below the plow depth. The exchangeable potassium was considered as most nearly representing that which is available to plants during a growing season. It was determined by extracting the soil with N/4 sodium acetate made up at pH 5.0 and determining the potassium in the extract by the cobalti-nitrite volumetric method.

The data taken from Table 1 are shown graphically in Fig. 2. Of the 72 cases studied, 67 showed greater quantities of exchangeable potassium in the surface soil. Five cases showed greater amounts in the subsoil, but these were, with one exception, within the limit of error for the determination. The mean difference between the surface soils and subsoils was 57 pounds and the odds against this difference being due to chance are greater than 10,000 to 1. Such evidence commands attention to the possible effects of erosion on the potash status of soils. Further studies contemplated will determine what properties and processes in the surface soil give rise to its higher exchangeable potassium content.

TABLE 1.—*Summary of sites and analyses.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs. 2 000,000		Key No.
					Long method	Rapid method	
			Site 1, State College, Center County				
2226	Hagerstown silt loam	Surface	Alfalfa sod	2.04	155	250	1
2234	Hagerstown silt loam	Surface	Legume cover crop	1.50	176	250	2
			Site 2, Scotland, Franklin County				
2242	Hagerstown clay loam	Surface	Cultivated	1.07	107	250	3
2241	Hagerstown clay loam	Surface	Cultivated	1.01	113	200	4
			Site 3, Greencastle, Franklin County				
2238	Hagerstown silt loam	Surface	Sod 40 years	1.74	185	350	5
2247	Hagerstown silt loam	Subsoil		0.30	158	300	7
2237	Hagerstown silt loam	Surface	Sod 15 years	1.53	91	200	6
			Site 4, Waynesboro, Franklin County				
2243	Murrill loam	Surface	Sod	1.67	189	300	8
2248	Murrill loam	Subsoil		0.46	86	50	10
2245	Murrill loam	Surface	Cultivated	0.70	53	50	9
			Site 5, Mann's Choice, Bedford County				
2265	Gilpin shaley silt loam	Surface	Sod	1.72	93	200	11
2266	Gilpin shaley silt loam	Subsoil		0.79	38	50	14
2261	Gilpin shaley silt loam	Surface	Cultivated	1.48	80	150	12
2262	Gilpin shaley silt loam	Surface	Cultivated	1.42	85	200	13

		Site 6 New Paris, Bedford County					
2259	Gilpin silt loam	Surface	Sod	2.84	82	200	15
2260	Gilpin silt loam	Subsoil		1.92	109	150	20
2253	Gilpin silt loam	Surface	Cultivated	1.12	80	100	16
2254	Gilpin silt loam	Subsoil		0.50	32	50	19
2252	Gilpin shaley silt loam	Surface	Cultivated	1.44	53	150	17
2258	Gilpin shaley silt loam	Surface	Cultivated	2.41	130	200	18
		Site 7 McKnightstown Adams County					
2274	Penn silt loam	Surface	Sod	1.95	199	300	21
2275	Penn silt loam	Subsoil		0.24	70	50	26
2273	Penn silt loam	Surface	Sod	1.84	205	300	22
2276	Penn silt loam	Surface	Sod	1.60	198	300	23
2269	Penn silt loam	Surface	Cultivated	1.76	183	200	24
2270	Penn silt loam	Surface	Cultivated	1.49	201	350	25
		Site 8 Pleasant Gap, Center County					
2285	Dekalb loam	Surface	Sod	2.10	92	200	27
2284	Dekalb loam	Subsoil		0.65	55	150	29
2281	Dekalb loam	Surface	Young sod	1.23	71	100	30
2279	Dekalb loam	Subsoil		0.33	40	50	28
		Site 9 Zullinger Franklin County					
2291	Hagerstown loam	Surface	Sod	1.69	188	300	31
2293	Hagerstown loam	Subsoil		0.29	61	100	32
		Site 10 Waynesboro Franklin County					
2309	Edgemont loam	Surface	Cultivated	1.10	91	200	33
2310	Edgemont loam	Subsoil		0.19	81	200	35
2311	Edgemont loam	Surface	Cover cropped	1.19	75	150	34
2312	Edgemont loam	Subsoil		0.26	45	100	37
2307	Edgemont loam	Subsoil	Woods	0.64	142	300	36
		Site 11, York, York County					
2302	Conestoga silt loam	Surface	Sod	2.11	127	250	38
2297	Conestoga silt loam	Subsoil		0.61	75	250	41
2300	Conestoga silt loam	Surface	Cultivated	0.96	80	250	39
2301	Conestoga silt loam	Surface	Cover cropped	1.70	81	250	40

TABLE 1—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Site 12, Arendtsville, Adams County				
2314	Penn loam	Surface	Sod	1.33	51	100	42
2292	Penn loam	Surface	Cultivated	0.59	65	150	43
2306	Penn loam	Surface	Cultivated	0.70	49	150	44
2305	Penn loam	Surface	Cultivated; later alfalfa	0.81	100	200	45
2305	Penn loam	Subsoil	Woods	0.64	88	200	46
			Site 13, Somerset, Somerset County				
2318	Dekalb sandy loam	Surface	Sod	3.57	203	300	47
2320	Dekalb sandy loam	Surface	Cultivated	1.69	100	100	48
2315	Dekalb silt loam	Surface	Cultivated	1.72	152	250	49
2317	Dekalb silt loam	Subsoil	Woods	0.38	51	50	50
			Site 14, Mars, Allegheny County				
2323	Westmoreland loam	Surface	Sod	1.92	110	250	51
2326	Westmoreland loam	Subsoil		0.27	44	100	55
2322A	Westmoreland loam	Surface	Cultivated	1.19	81	200	52
2324	Westmoreland loam	Subsoil		0.32	44	50	54
2322B	Westmoreland loam	Surface	Cultivated	1.08	83	100	53
			Site 15, Wexford, Allegheny County				
2342	Westmoreland loam	Surface	Sod	1.75	181	300	56
2341A	Westmoreland loam	Surface	Cultivated	1.03	89	100	57
2341B	Westmoreland loam	Subsoil		0.32	44	100	58

			Site 16, Baden, Beaver County				
2329	Gilpin loam	Surface	Sod	1.78	95	150	59
2328	Gilpin loam	Subsoil		0.54	48	100	61
2327	Gilpin loam	Surface	Young sod	2.10	76	100	60
			Site 17, North East, Erie County				
2332	Dunkirk sandy loam	Surface	Cultivated	1.57	105	150	62
2339A	Dunkirk sandy loam	Subsoil		0.30	18	50	66
2333	Dunkirk sandy loam	Surface	Cultivated	1.91	174	200	63
2339B	Dunkirk sandy loam	Subsoil	Cover cropped	0.57	56	100	67
2334A	Dunkirk sandy loam	Surface	Cover cropped	1.49	101	200	64
2334B	Dunkirk sandy loam	Surface	Cover cropped	1.34	72	100	65
			Site 18, North East, Erie County				
2344	Dunkirk sandy loam	Surface	Sod	2.19	138	250	68
2343	Dunkirk sandy loam	Surface	Sod	1.85	268	300	69
2338	Dunkirk sandy loam	Surface	Cultivated	1.17	97	200	70
			Site 19, North East, Erie County				
2345	Dunkirk sandy loam	Surface	Cultivated	2.06	50	50	71
2349	Dunkirk sandy loam	Surface	Cover cropped	1.46	67	200	72
2346	Dunkirk sandy loam	Subsoil		0.58	29	100	73
			Site 20, Mercer, Mercer County				
2351	Volusia silt loam	Surface	Sod	2.73	109	300	74
2354	Volusia silt loam	Surface	Cover cropped	1.45	153	200	75
2355	Volusia silt loam	Subsoil		1.58	168	250	76
			Site 21, Danville, Montour County				
2357	Dekalb sandy loam	Surface	Sod	1.10	44	50	77
2362	Dekalb sandy loam	Surface	Cultivated	0.79	54	50	78
2363	Dekalb sandy loam	Subsoil		0.34	59	50	79
			Site 22, Dallis, Luzerne County				
2364	Volusia silt loam	Surface	Sod	3.04	39	50	80
2365	Volusia silt loam	Surface	Cultivated	1.48	38	50	81
2366	Volusia silt loam	Surface	Young sod	1.74	43	50	82
2367	Volusia silt loam	Subsoil	Woods	0.61	36	50	83

TABLE I.—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs. 2,000,000		Key No.
					Long method	Rapid method	
			Site 23, Falls, Wyoming County				
2376	Volusia silt loam	Surface	Sod	2.05	26	50	84
2377	Volusia silt loam	Surface	Cultivated	1.57	37	50	85
2374	Volusia silt loam	Surface	Cultivated	1.51	54	50	86
2375	Volusia silt loam	Subsoil		0.44	22	50	87
			Site 24, Wapwollopen, Luzerne County				
2378	Volusia silt loam	Surface	Sod	2.23	52	50	88
2383	Volusia silt loam	Surface	Sod	2.44	17	150	89
2381	Volusia silt loam	Subsoil	Woods	0.57	65	50	90
			Site 25, Hamburg, Berks County				
2401	Berks shaly loam	Surface	Sod	1.97	224	300	91
2386	Berks shaly loam	Surface	Cultivated	0.81	97	100	92
2384	Berks shaly loam	Subsoil		0.13	46	50	93
			Site 26, Ephrata, Lancaster County				
2406	Hagerstown silt loam	Surface	Sod	1.98	110	100	94
2407	Hagerstown silt loam	Subsoil		—	36	50	—
2402	Hagerstown silt loam	Surface	Young sod	2.15	151	400	95
2405	Hagerstown silt loam	Surface	Sod	1.12	98	250	96
			Site 27, Allentown, Lehigh County				
4661	Berks shaly loam	Surface	Complete fertilizer cultivated	2.07	335	350	97
4662	Berks shaly loam	Subsoil		1.25	152	200	98
4663	Berks shaly loam	Surface	Complete fertilizer sod	4.15	493	350	99
4664	Berks shaly loam	Subsoil		2.23	374	300	100

			Site 28, Biglerville, Adams County				
4665	Ashe loam	Surface	Nitrogen only, sod	1.65	94	150	101
4666	Ashe loam	Subsoil		0.50	102	150	102
4667	Ashe loam	Surface	Nitrogen only, cultivated	1.79	70	100	103
4668	Ashe loam	Subsoil		0.62	74	150	104
4669	Ashe loam	Surface	Nitrogen only, cultivated	1.15	53	100	105
4670	Ashe loam	Subsoil		0.47	46	150	106
4671	Ashe loam	Surface	Manure, cultivated	1.32	136	150	107
4672	Ashe loam	Subsoil		0.46	52	150	108
			Site 29, Arentsville, Adams County				
4673	Penn loam	Surface	Complete fertilizer cover cropped	1.49	182	350	109
4674	Penn loam	Subsoil		0.40	136	250	110
4675	Penn loam	Surface	Complete fertilizer cover cropped	1.84	336	350	111
4676	Penn loam	Subsoil		0.52	220	300	112
4677	Penn loam	Surface	Complete fertilizer cover cropped	1.07	93	150	113
4678	Penn loam	Subsoil		0.35	57	250	114
4750	Penn loam	Surface	Complete fertilizer cover cropped	1.65	285	300	150
4751	Penn loam	Subsoil		0.38	190	200	151
4752	Penn loam	Surface	Complete fertilizer cover cropped plus additional potash	1.72	214	250	152
4753	Penn loam	Subsoil		0.36	89	100	153
4754	Penn loam	Surface	Complete fertilizer cover cropped	1.84	172	250	154
4755	Penn loam	Subsoil		0.65	100	100	155
			Site 30, Arendtsville, Adams County				
4679	Penn loam	Surface	No fertilizer, sod	1.31	113	200	115
4680	Penn loam	Subsoil		0.26	14	50	116
			Site 31 Arendtsville, Adams County				
4681	Porters silt loam	Surface	Manure, cover cropped	1.39	112	150	117
4682	Porters silt loam	Subsoil		0.25	19	50	118
			Site 32, Gardners, Adams County				
4683	Chester silt loam	Surface	Nitrogen only, cover cropped	1.53	175	250	119
4684	Chester silt loam	Subsoil		0.25	87	200	120
4685	Porters silt loam	Surface	Nitrogen only, cover cropped	1.72	85	100	121
4686	Porters silt loam	Subsoil		0.30	36	50	122
			Site 33, Biglerville, Adams County				
4688	Penn sandy loam	Surface	Manure, cultivated	1.41	233	200	123
4689	Penn sandy loam	Subsoil		0.35	72	50	124
4690	Penn sandy loam	Surface	Manure, sod	1.77	303	200	125
4691	Penn sandy loam	Subsoil		0.52	83	100	126

TABLE 1.—*Continued.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Site 34, Fairfield, Adams County				
4692	Porters silt loam	Surface	Intermediate potash, treatment	2.21	180	200	127
4693	Porters silt loam	Subsoil		1.09	36	50	128
			Site 35, Adams County				
4694	Porters silt loam	Surface	Nitrogen only, sod	1.70	145	50	129
4695	Porters silt loam	Subsoil		0.41	41	50	130
4756	Porters silt loam	Surface	No treatment, cover cropped	1.36	55	50	156
4757	Porters silt loam	Subsoil		0.43	11	50	157
4758	Porters silt loam	Surface	Manure, cover cropped	1.19	575	250	158
4759	Porters silt loam	Surface	Sawdust, cover cropped	1.47	53	50	159
4760	Porters silt loam	Surface	No treatment, cover cropped	1.48	46	50	160
4761	Porters silt loam	Subsoil		0.47	17	50	161
			Site 36, Stewartstown, York County				
4696	Manor loam	Surface	Nitrogen only, cover cropped	1.64	85	50	131
4697	Manor loam	Subsoil		0.15	23	50	132
4698	Manor loam	Surface	Complete fertilizer, cover cropped	1.41	96	50	133
4699	Manor loam	Surface	Complete fertilizer, cover cropped	1.21	87	50	134
4700	Manor loam	Subsoil		0.25	32	50	135
4742	Manor loam	Surface	Cultivated field, no fertilizer	1.41	55	50	142
4743	Manor loam	Subsoil		0.26	48	50	143
4744	Manor loam	Surface	Reforested area	1.66	127	150	144
4745	Manor loam	Subsoil		0.36	40	50	145
4746	Manor loam	Surface	Reforested area	1.15	48	50	146
4747	Manor loam	Subsoil		0.24	17	50	147
4748	Manor loam	Surface	Complete fertilizer	1.72	47	50	148
4749	Manor loam	Subsoil	General rotation	0.49	32	50	149

			Site 37, Stewartstown, York County				
4701	Manor loam	Surface	Straw mulch	1.33	140	150	136
4702	Manor loam	Subsoil		0.23	33	50	137
			Site 38, Loganville, York County				
4738	Chester silt loam	Surface	No treatment, sod	1.52	121	100	138
4739	Chester silt loam	Subsoil		0.33	91	50	139
4740	Chester silt loam	Surface	No treatment, cultivated	1.62	103	50	140
4741	Chester silt loam	Subsoil		0.38	63	50	141
			Site 39, Franklin County				
4762	Duffield silt loam	Surface	No treatment cultivated	1.09	79	50	162
4763	Duffield silt loam	Subsoil		0.29	52	50	163
			Unit 40, Girard, Erie County				
4716	Dunkirk loam	Surface	Complete fertilizer, cover cropped	1.35	68	50	164
4717	Dunkirk loam	Subsoil		1.13	57	100	165
			Unit 41, Girard, Erie County				
4718	Dunkirk sandy loam	Surface	Complete fertilizer, cultivated	1.38	75	100	166
4719	Dunkirk sandy loam	Subsoil		0.44	51	50	167
4720	Clyde silt loam	Surface	No fertilizer, cover cropped	3.28	58	50	168
4721	Clyde silt loam	Subsoil		0.61	51	50	169
			Unit 42, Girard, Erie County				
4722	Dunkirk gravelly loam	Surface	Complete fertilizer, cover cropped	1.49	100	150	170
4723	Dunkirk gravelly loam	Subsoil		0.63	55	50	171
4724	Dunkirk gravelly loam	Surface	Complete fertilizer, cover cropped	1.46	150	250	172
4725	Dunkirk gravelly loam	Subsoil		0.29	30	50	173

TABLE 1.—*Concluded.*

Lab. No.	Soil type	Horizon	Treatment	% Carbon	Exchangeable K Lbs./2,000,000		Key No.
					Long method	Rapid method	
			Unit 43, Girard, Erie County				
4726	Dunkirk sandy loam	Surface	Complete fertilizer	0.67	54	150	174
4727	Dunkirk sandy loam	Subsoil	Cover cropped	0.25	20	50	175
			Unit 44, Girard, Erie County				
4728	Dunkirk gravelly loam	Surface	Newly cultivated ground	1.65	97	150	176
4729	Dunkirk gravelly loam	Subsoil		0.88	38	50	177
4730	Dunkirk gravelly loam	Surface	Newly cultivated ground	2.33	211	350	178
4731	Dunkirk gravelly loam	Subsoil		0.68	230	350	179
			Unit 45, Girard, Erie County				
4732	Dunkirk gravelly loam	Surface	No fertilizer	1.42	105	200	180
4733	Dunkirk gravelly loam	Subsoil	Cultivated	0.63	16	50	181
			Unit 46, East Springfield, Erie County				
4734	Dunkirk sandy loam	Surface	No fertilizer	1.27	18	50	182
4735	Dunkirk sandy loam	Subsoil	Cultivated	0.36	7	50	183
			Site 47, North Girard, Erie County				
4736	Dunkirk sandy loam	Surface	Intermediate K application	1.68	69	200	184
4747	Dunkirk sandy loam	Subsoil		0.49	20	50	185

RELATION BETWEEN AMOUNT OF ORGANIC MATTER IN ORCHARD SOILS AND EXCHANGEABLE POTASSIUM

Since it was shown conclusively that surface soils contain more replaceable potassium than subsoils and since it is well known that as erosion of surface soil gradually increases more and more subsoil is mixed into the surface by plowing, it seemed well to compare the organic content with exchangeable potassium.

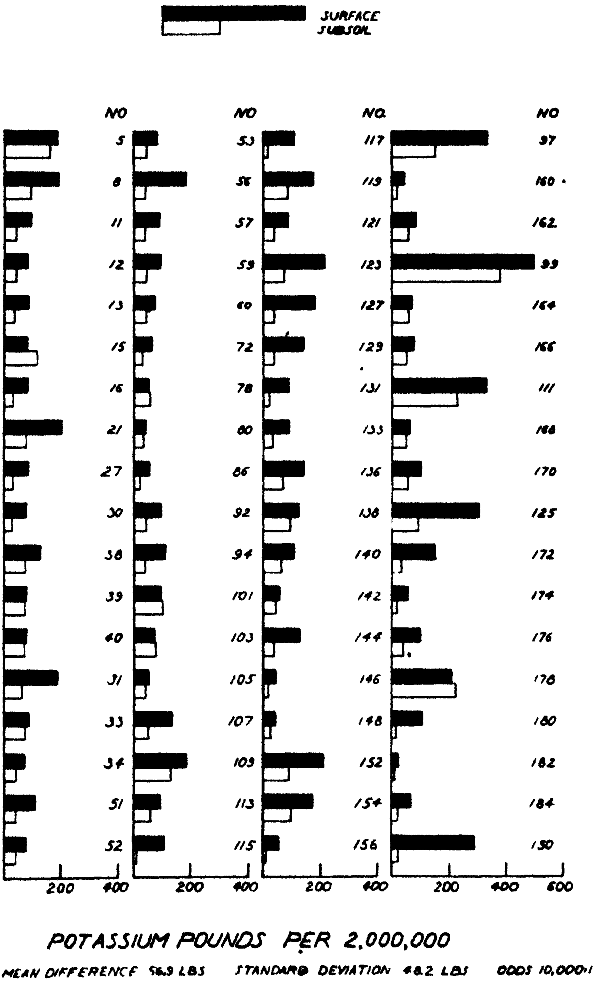

FIG. 2.—Replaceable potassium; surface vs. subsoil.

The organic content was determined by the chromic acid titration procedure of Schollenberger (4) as modified by Tuirin (7). The exchangeable potassium was determined as outlined above. Certain of the data from Table 1 are shown graphically as Fig. 3. In spite of the fact that several differences occur, such as difference in soil type, in

cover cropping, and in fertilizing and manuring, the correlation is reasonably good, the coefficient of correlation being .501 ± .03.

In order to decrease the error due to grouping in one correlation distribution soils of several series, additional graphs were prepared showing the relationships between organic content and exchangeable potassium within soil families or related series. Within a given series or family the correlation in most cases is closer than where all series are grouped on a single distribution. These correlations were as follows: Dunkirk soils, .49 ± .07; Penn and Berks soils, .83 ± .05; Dekalb and Gilpin soils, .61 ± .07; and Chester Manor and Porters soils, .68 ± .07.

These findings are in agreement with a study made in 1934 and 1935 on soils of the rim experiments conducted by the Pomology division. In this experiment varying amounts of green rye are added to the surface of the soil in rims growing trees. It was found that as the amount of green rye added increased, the amount of replaceable potassium increased (Table 2.)

TABLE 2.—*Replaceable potassium in pounds per acre in surface and subsoil as influenced by varying amounts of rye added as green manure*

N used	Soil layer	Green rye added*		
		0	3	6
I†	Surface	350	350	400
	Subsoil	170	180	180
II	Surface	200	300	300
	Subsoil	150	170	300
III	Surface	200	250	350
	Subsoil	230	250	250

*Figures denote relative amounts green material added
†Numerals denote increasing amounts of nitrogen used

In every case it can be noted that the larger additions of green rye increased the amount of replaceable potassium, attributable either to potassium contained in the organic matter added or to release from the soil, or both.

COMPARISON BETWEEN DIFFERENT SOIL SERIES IN REGARD TO REPLACEABLE POTASSIUM

When similar soil series are plotted with reference to organic content and replaceable potassium, a better correlation is generally obtained than when all series are grouped together, as in Fig. 3. This suggests that the mineralogical parentage of a soil is a factor to be considered. Accordingly, the average replaceable potassium content for all surface and subsoil samples of each series was determined and presented in Table 3.

The Penn and Hagerstown series contain relatively large amounts of replaceable potassium in both surface and subsoil, indicating that the nature of the parent material has a dominant influence since there

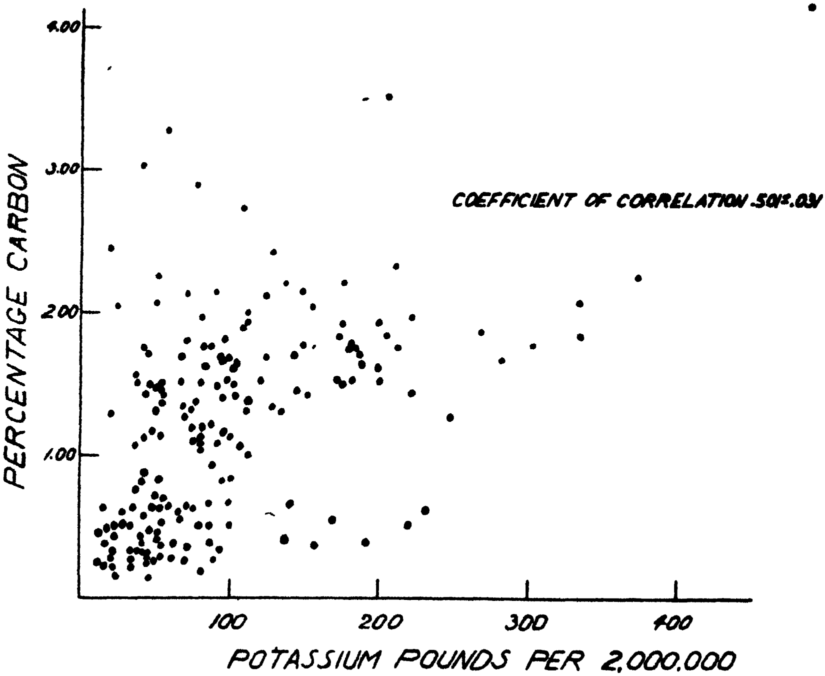

FIG. 3.—Exchangeable potassium vs. organic matter in 185 Pennsylvania orchard soils.

TABLE 3.—*The average amounts of exchangeable potassium in certain Pennsylvania soils.*

No.	Soil series	Lbs. /2,000,000 average potassium		No. of samples
		Surface	Subsoil	
1	Penn	176	102	29
2	Hagerstown	130	82	12
3	Dunkirk	114	59	32
4	Dekalb	102	51	10
5	Gilpin	86	57	13
6	Volusia	57	73	14
7	Porters	97	27	13
8	Manor-Chester association	86	32	15

were poorly fertilized orchards within this group as well as in other soil series. The Chester-Manor association, the Porters, and the Volusia appear to be definitely lower in replaceable potassium in both surface and subsoil. The Dekalb, Gilpin, and Dunkirk are intermediate in this respect. A further investigation into the nature of the colloidal matter in some of the high and low potassium series is under way.

It is of interest to note that two soils showing the lowest average replaceable potassium, namely, the Chester-Manor association and the Porters, are the soils upon which Anthony and Dunbar (2) first located potassium deficiency symptoms in peach trees. It should be emphasized, however, that certain soil characteristics, such as the porosity and depth of root penetration, should be considered in interpreting the analysis. Doubtless higher potassium levels are needed in those soils which have dense subsoils.

COMPARISON OF RAPID TESTS FOR REPLACEABLE SOIL POTASSIUM WITH QUANTITATIVE PROCEDURES

If deficiencies of potassium are of frequent occurrence, there will be a real need for soil tests performed on short notice. Since rapid tests are now available and since their applicability has been questioned by some, it was decided to determine just how accurate they are when compared with the longer quantitative methods. Accordingly, the sodium acetate extracts obtained from all samples were tested by the rapid method essentially as outlined by Bray (1), except that the turbidity of the potassium cobalt nitrite precipitate was determined by comparing it with standards of known concentration rather than by the use of improvised comparators. Another portion of the same extract was analyzed accurately by the cobaltinitrite volumetric procedure now in common use (3). Fig. 4 shows the correlation between the rapid and the quantitative procedures.

It is clear from the distribution that the rapid procedure in general gives values higher than the quantitative procedure and that it would not be sufficiently accurate for precise experimental work. However, there is a reasonably good correlation between the two procedures, as shown by the coefficient of correlation, $\pm .78 \pm .02$, and since no one at present can tell what is the threshold concentration for potassium in the soil, it is clear that the rapid method may be used with safety for rough diagnostic purposes. By the use of the rapid or quantitative procedure one can pick soils in which potassium deficiency is likely to occur, but he cannot say positively that it will occur on such soil.

FOLIAGE ANALYSIS AS INDICATIVE OF POTASSIUM DEFICIENCY AND RESPONSE

In order to determine whether or not there was any relationship between the potassium content of the leaf, expressed as percentage or as milligrams of potassium per leaf, and the deficiency symptoms or the amount of replaceable potassium in the soil, leaf samples were taken from representative trees from every orchard where soil samples were taken.

In all cases leaves were taken from the mid-portions of the current years growth. They were dried, ashed, and analyzed for potassium. It was realized at the outset that the leaf samples were taken too late in the season, at about the middle of August, and insufficient fertilizer combinations were available to apply the foliage diagnosis principles as set forth by Thomas (6). Nevertheless, we sought to gain some information, crude as it might be.

There was no connection between the potassium content of the leaf expressed as percentage of potassium or milligrams of potassium per leaf and the amount of replaceable potassium in the soil (Tables 4 and 5). This might be expected since the percentage of any element present in tissue is expressed upon the total growth which in itself depends upon all growth factors, nutritional and otherwise. In several cases the application of potassium in manure or inorganic

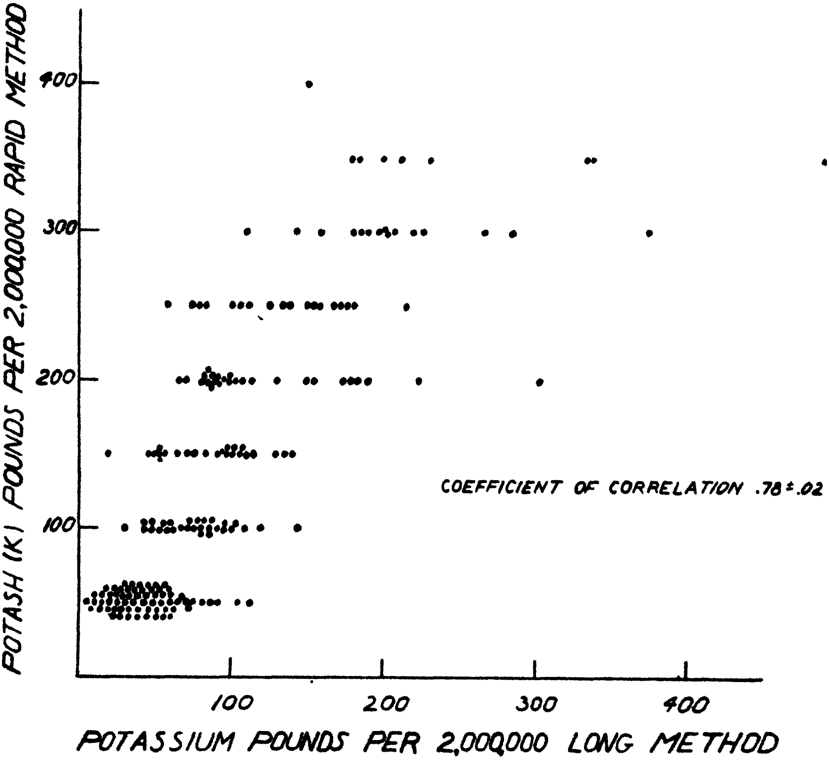

FIG. 4.—Rapid vs. long method for potassium.

salts showed no change in the potassium status of the soil as measured by exchange analysis, but the effects of such applications were apparent in the analysis of the leaves. Table 6 summarizes the data from two orchards not far apart on the Chester-Manor soil, one owned by Russel Shaw, the other by Howard Anderson. Here one grower has quite definitely experienced a potassium deficiency and has achieved responses from application of potash while the other has had none of the symptoms. The latter has used a heavy straw mulch. In Table 6 cases 1, 2, and 3 are from the Shaw orchard and case 4 from the Anderson orchard.

Case 1, receiving no added potassium, and cases 2 and 3, receiving additions one year only in the form of fertilizer and manure, show no essential difference in the amounts of replaceable potassium in the

TABLE 4.—*Comparison of apple leaves and soil analyses under varied treatments.*

Soil series	Treatment	Variety	Leaf % K	Leaf Mgms K/leaf	K Lbs./2,000,000 surface soils, Long method	Lab. No.
Ashe	Nitrogen only, sod	York Imperial	1.28	4.5	94	4665
Ashe	Nitrogen only, sod	York Imperial	1.17	3.7	70	4667
Ashe	Nitrogen only, cultivated	Stayman Winesap	1.67	6.7	53	4669
Ashe	Manure, cultivated	Rambo	1.81	10 1	136	4671
Berks	Complete fertilizer, sod	Early (unidentified)	1.33	7.7	494	4663
Chester	Nitrogen only, cover cropped	Early (unidentified)	1.51	5.6	175	4683
Chester	No treatment, sod	Early (unidentified)	1.23	3.5	121	4738
Clyde	No treatment, cover cropped	Early McIntosh	0.47	1.8	58	4720
Duffield	No treatment, cultivated	Grimes Golden	1.40	4 2	79	4762
Manor	Nitrogen only, cover cropped	Rambo	0.74	3 7	85	4796
Manor	Complete fertilizer, cover cropped	Rambo	0.42	1.6	96	4798
Penn	Complete fertilizer, cover cropped	Jonathan	1.19	3.8	182	4673
Penn	Complete fertilizer, cover cropped	Jonathan	1 26	4.3	336	4675
Penn	Complete fertilizer, cover cropped	Wealthy	0.95	3.4	93	4677
Penn	No fertilizer, sod	York Imperial	1.06	3.4	113	4679
Penn	Manure, sod	Unidentified	1 12	4.2	303	4690
Penn	Complete fertilizer, cover cropped plus additional potassium	Grimes Golden	0.99	4.1	285	4750
Penn	Complete fertilizer, cover cropped plus additional potassium	Jonathan	0.67	1.8	214	4752
Porters	Manure, cover cropped	Unidentified	0.97	3.6	112	4681
Porters	Nitrogen only, cover cropped	Unidentified	1.04	4.3	85	4685
Porters	Intermediate potash treatment	Dutchess	0.89	4.6	180	4692
Porters	Nitrogen only, sod	Jonathan	0.78	2.9	145	4694

Coefficient of correlation between percentage of potassium in the leaf and exchangeable potassium in the soil was 29 ± 12.

TABLE 5.—*Comparison of peach leaves and soil analyses under varied treatments.*

Soil series	Treatment	Variety	Leaf		K Lbs. 2,000,000 surface soils Long method	Lab. No.
			% K	Mgms K leaf		
Berks	Complete fertilizer, cultivated	Unidentified	1.70	5.2	335	4661
Dunkirk	Complete fertilizer, cover cropped	Rochester	0.93	2.9	68	4716
Dunkirk	Complete fertilizer, cultivated	South Haven	1.13	4.7	75	4718
Dunkirk	Complete fertilizer, cover cropped	Rochester	1.89	5.8	100	4722
Dunkirk	Complete fertilizer, cover cropped	Elberta	1.56	5.4	150	4724
Dunkirk	Complete fertilizer, cover cropped	South Haven	1.52	7.1	54	4726
Dunkirk	Newly cultivated ground	Rochester	2.42	9.1	97	4728
Dunkirk	Newly cultivated ground	Rochester	2.46	10.6	211	4730
Dunkirk	No fertilizer, cultivated	Rochester	0.60	1.7	105	4732
Dunkirk	No fertilizer, cultivated	Rochester	0.56	1.4	18	4734
Dunkirk	Intermediate K application	Rochester	1.20	4.4	69	4736
Manor	Nitrogen only, cover cropped	Elberta	0.71	1.6	85	4696
Manor	Complete fertilizer, cover cropped	Elberta	1.07	3.4	96	4698
Manor	Complete fertilizer, cover cropped	Unidentified	1.35	5.9	87	4699
Manor	Straw mulch	Unidentified	1.81	5.8	140	4701
Penn	Manure cultivated	Unidentified	2.16	6.5	223	4688
Porters	No treatment, cover cropped	Unidentified	1.34	4.9	55	4756
Porters	Manure, cover cropped	Unidentified	1.56	6.7	575	4758

Coefficient of correlation between percentage of potassium in the leaf and exchangeable potassium in the soil was 35 ± 12.

TABLE 6.—*Effects of soil treatment on Elberta peach leaf analyses and upon the replaceable potassium in the soil.*

Case No.*	Carbon, %	K in leaf, %	Mgms K in leaf	Lbs. K in surface soil	Lbs. K in subsoil
1	1.64	0.71	1.64	85	23
2	1.41	1.10	3.43	96	—
3	1.21	1.35	5.94	87	32
4	1.33	1.81	5.84	140	33

*Treatments:

1—4 lbs. $NaNO_3$ annually per tree

2—4 lbs $NaNO_3$ annually per tree, 1938 manure, 1937 38 500 lbs. 4-8-10 per acre, 3 lbs KNO_3 per tree.

3—4 lbs $NaNO_3$ annually per tree, 1938 manure, 1937-38 500 lbs. 4-8 10, 2,000 lbs 4-8 7 in 1920's.

4—Straw mulch and nitrogen for last 5 years.

soil. The amount so added is not large enough to make a significant difference in the replaceable potassium of the soil when consideration is given to that lost through leaching and that removed by the trees and cover crop and the possibility of some being fixed in non-replaceable form. However, the compositon of the leaf readily reveals added potassium both in percentage and in total milligrams per leaf, the percentage in the leaf having increased from 0.71 to 1.35 and the total milligrams of potassium per leaf from 1.64 to 5.94. This is in agreement with numerous observations which we have made, namely, that a single application of potash salt or manure sufficient to influence the plant does not make a measurable difference in the amount of replaceable potassium in the soil. This must not be considered as demonstrating that testing is valueless. On the contrary it may indicate those levels of replaceable potassium in the soil which, when all other soil factors are properly evaluated, indicate the need of attending to the potash question.

In case 4, heavy mulching with straw with no applied potassium has resulted in no symptoms of deficiency in the leaf either by appearance or composition, and an increased quantity of exchangeable soil potassium. Wander and Gourley (8) have likewise found the straw mulch to enhance the available potassium content of the soil.

A case contrary to the one just described is that of the Landis Fruit Farm on Dunkirk gravelly loam in Erie County. Here one block of trees was affected with some physiological disorder diagnosed as a possible potassium deficiency. Another block on a soil definitely higher in organic matter was found to show none of these symptoms. Their relative analyses are given in Table 7.

TABLE 7.—*Comparison between an area showing a physiological deficiency and an adjacent one not showing such deficiency on Dunkirk gravelly loam.*

Case	Lbs. K, surface	Lbs. K, subsoil	Carbon, %	K in leaf, %	Mgms K in leaf
No symptoms .	211	230	2.33	2.5	10.6
Symptoms present	97	38	1.65	2.4	9.1

At first sight the great difference between the affected and unaffected areas in replaceable potassium would substantiate the idea of a

potassium deficiency. However, this is a very permeable soil and probably will tolerate a lower level of potassium than would a more compact soil. The leaf analyses do not suggest potassium deficiency, the differences being scarcely significant and both quite high in comparison with peach leaves in general. A field trial is greatly needed to help interpret this type of result.

Nearly all samples of the Penn series were rather high in replaceable potassium while the leaf analyses do not appear to be above the average some being quite low. The cause of this is a matter for speculation, but its consistancy may lead to the conclusion that a high soil level of potassium availability cannot be an absolute criterion of a possible sufficiency. Conditions restricting the root systems would in all probability be expected to require higher levels of available nutrients for the tree to continue normal growth. The Penn soil has a compact subsoil and a readily dispersed surface soil.

SUMMARY AND CONCLUSIONS

1. Soil samples and leaf samples were obtained from 47 commercial orchards from different districts of Pennsylvania.

2. Surface soils were definitely higher than subsoils in replaceable potassium and loss of top soil by erosion is a factor in increasing the need of applied potassium.

3. Certain soil series were found to contain more replaceable potassium than others. A few were notably low.

4. The amount of replaceable potassium is related to the organic matter content of the soil.

5. The rapid method for determining replaceable potassium compares favorably with the quantitative cobalti-nitrite method and is satisfactory for determining the general level of soil potassium.

6. Leaf analyses did not correlate with the replaceable soil potassium but in some cases gave indications of the effects of potash application which could not be detected by exchange analyses.

7. Field experiments in which potassium salts are added to certain trees and not to others should be started on as many soil series as practicable. These are needed because so-called deficiency symptoms may be of dubious reliability.

LITERATURE CITED

1. BRAY, R. H. A test for replaceable and water-soluble potassium in soils. Jour. Amer. Soc. Agron., 24:312–316. 1932.
2. DUNBAR, C. O., and ANTHONY, R. D. Two cases of potassium deficiency in peach orchards in south central Pennsylvania. Proc. Amer. Soc. Hort. Sci., 35:320–325. 1938.
3. MILNE, G. Cobaltinitrite method of estimating potassium in soil extracts. Jour. Agr. Sci., 19:541–552. 1929.
4. SCHOLLENBERGER, C. J. Determination of soil organic matter. Soil Science, 31:483–486. 1931.
5. SHAW, CHARLES F. The soils of Pennsylvania. Pa. State College Bul. 132. 1914.
6. THOMAS, WALTER. Foliar diagnosis: Principles and practice. Plant Phys., 12:571–599. 1937.

7. TUIRIN, J. W. A new modification of the volumetric method of determining soil organic matter by means of chromic acid. Pedology, 5–6:36. 1931. (Russian with English summary.)
8. WANDER, I. W., and GOURLEY, J. H. Available potassium in orchard soils as affected by a heavy straw mulch. Jour. Amer. Soc. Agron., 30:438–446. 1938.
9. SHAULIS, N. J., and MERKLE, F. G. Some effects of orchard soil management practices upon the soil. Pa. Agr. Exp. Sta. Bul. 373. 1939.

SOME ASPECTS OF THE PHYSIOLOGY AND NUTRITION OF TOBACCO[1]

W. W. GARNER[2]

IN carrying out fairly extensive fertilizer experiments with tobacco over a period of years in cooperation with several of the states in which this crop is of commercial importance, it soon became apparent that results to be obtained by the old conventional methods of conducting field plat tests and recording the fertilizer effect merely in terms of final crop yields and values could not be expected to furnish a basis for determining the mode of action of the fertilizer. It seemed clear that there was urgent need of developing a physiological approach to the fertilizer problem which would make possible a reasonably clear analysis of the biochemical and biophysical conditions associated with application of fertilizer to the soil and the mode of action of the fertilizer elements on plant growth and development. Our attention was first directed sharply to this situation by some unexpected results obtained in what seemed to be a simple fertilizer experiment of the old type which was begun in 1912 on Durham sandy loam or closely related soil type at the Oxford, N. C., tobacco station. The experiment, which at that time was considered to be a "potash test", involved adding to the soil four different rates of potash derived, in duplicate series, from high grade sulfate and muriate. The basal fertilizer treatment supplied nitrogen in the form of dried blood and phosphoric acid derived from a dicalcic phosphate.

Contrary to expectations, the two forms of potash did not give the same results (Table 1). The sulfate produced lower yields, there was a tendency toward a breakdown of the leaf tissue which is now known as drought spot, and, more important, a typical chlorosis of the leaves developed which has come to be known popularly as "sand drown". After further investigation the chlorosis was found to be due to magnesium deficiency and the results of the study were published in 1923 (1).[3] So far as is known this is the first recorded instance of the occurrence of magnesium deficiency in a field crop with accompanying characteristic deficiency symptoms in the plant. Occurrence and symptoms of magnesium hunger in corn, cotton, and soybeans also were reported (2).

The results obtained make it clear that, properly speaking, in reality this experiment was not a potash test at all; it was merely a

[1]Contribution from the Division of Tobacco and Plant Nutrition, U. S. Dept. of Agriculture. Most of the experimental data presented herein were obtained in connection with field experiments conducted in cooperation with the North Carolina Department of Agriculture and Experiment Station at the Oxford Tobacco Station and with the Maryland Agricultural Experiment Station at the Upper Marlboro field station. Also presented at the annual meeting of the Society held in Washington, D. C., November 16, 1938. Received for publication January 20, 1939.

[2]Principal Physiologist. Acknowledgment is made of effective cooperation on the part of J. E. McMurtrey, Jr., C. W. Bacon, J. D. Bowling, Jr., D. E. Brown, E. G. Moss, and W. M. Lunn. Brief reference is also made to the work of R. A. Steinberg on the mineral nutrition of *Aspergillus niger*.

[3]Figures in parenthesis refer to "Literature Cited", p. 471.

comparative test of two potash salts. Instead of a single variable there were three, namely, potassic, chloride, and sulfate ions, and interpretation of results in terms of potassium alone is not possible. It was found that failure of magnesium deficiency symptoms to appear in the plats receiving muriate of potash was due to the indirect effect of the chloride ion in making available a portion of the small magnesium reserve in the soil. It was shown, also, that chlorides in the tissue of the leaf have a tendency to prevent drought spot injury in addition to stimulating growth (3).

TABLE 1.—*Results of "potash tests," Oxford, N. C., illustrating effects of the anions of sulfate and muriate of potash.**

Pounds of potash applied as		Average yield† of tobacco in lbs., 1917 24 with		Average value‡ of crop, 1917–24 with		Pounds of sulfur (SO_3) applied as potassium sulfate	Pounds of chlorine applied as potassium chloride
Sulfate	Muriate	Sulfate	Muriate	Sulfate	Muriate		
—	—	—	—	—	—	0	0
12	12	493	612	$122	$161	10	11
24	24	617	682	$162	$206	20	22
36	36	619	710	$169	$231	31	33
80	80	645	714	$155	$215	68	73

*Basal treatment 800 pounds 4–8–0; nitrogen from dried blood, phosphoric acid from dicalcic phosphate (precipitated bone).
†Average yield of check 426 lbs.
‡Average value of check $84.

Since this experiment conclusively proved that for this soil a product supplying only the three elements nitrogen, phosphorus, and potassium does not constitute a complete fertilizer, it seemed necessary to inquire into the basis on which this commonly accepted definition of the complete fertilizer for tobacco as well as for other crops rests. Ash analyses of standard types of tobacco of normal growth disclose that of the six macro elements long recognized as essential to the plant, the content of calcium is similar to that of potassium and the content of magnesium and sulfur is similar to that of phosphorus while the nitrogen content is intermediate. In other words, the crop requirements as to the two groups of elements are about the same (Table 2). Turning to the light sandy and sandy loam soils on which so much of the tobacco crop is grown, especially those of the Atlantic Coastal Plain, available analyses, though limited, indicate that in general the content of calcium, magnesium, and sulfur is likely to be no greater, and may be much less, than the content of nitrogen, phosphorus, and potassium (7, 9). (See Table 2.) This situation suggests that for normal crop production the soil's supply of the first-named group is quite as likely to be deficient as the supply of the last-named elements, except that observation indicates rainfall has a greater effect on evidence of deficiency of sulfur in the crop than of the other five elements.

Fairly extensive tests have confirmed this assumption in three ways, *viz.*, (a) when any one of the three elements in question is omitted from the fertilizer the crop frequently manifests characteristic

TABLE 2.—*Relative quantities of the several macro elements required by the tobacco crop and their relative content in typical light tobacco soils.*

Tobacco type	Pounds in normal crop of 1,000 pounds leaf and 500 pounds of stalks					
	N	P_2O_5	K_2O	CaO	MgO	SO_3
Flue-cured (cigarette)	37	9	45	45	10	10
Connecticut Valley (cigar)*	65	11	121	74	13	24
Soil type	**Percentage content of soil**					
Norfolk fine sandy loam (0–16 in.)	0.04	0.04	0.05	0.03	Trace	0.05
Tifton fine sandy loam (0 12 in.)	0.04	0.04	0.10	0.05	Trace	0.06
Portsmouth fine sandy loam (0 12 in.)	0.05	0.05	0.06	Trace	Trace	0.03
Durham sandy loam (0 10 in.)	—	0.12	3.96	0.89	0.19	0.06
Merrimac sandy loam	0.15	0.32	1.44	1.03	0.50	—

*The actual average yield of Connecticut Valley cigar binder leaf is about 1,500 pounds, with corresponding increase in mineral requirements

deficiency symptoms similar to those obtained in solution cultures; (b) under such treatment the depression in growth is likely to be as great as when nitrogen, phosphorus, or potassium is omitted; and (c) ash analysis shows in the crop a much reduced content of the element omitted in the fertilizer (Table 3). Accordingly, it would seem that for these soils a complete fertilizer must contain all of the six elements under consideration and in quantities of the same order of magnitude. Of course in the past, with the use of complex fertilizer materials, this requirement has been largely complied with, though for the most part unintentionally. There appears to be no real basis for separating the six elements into groups of major and minor, or primary and secondary, elements; rather, all may well be placed on the same footing (Fig. 1). In our present tobacco fertilizer work consideration is given each of these elements from the standpoint of introducing into eact test as far as possible only a single variable with respect to the plant food supply (Table 3). This happens to be a matter of special importance in the case of tobacco since the relative supply of each of the six elements is capable of influencing the quality and commercial value of the crop.

Plant physiologists have long considered that plants may be cultured successfully in three-salt solutions if the salts supply nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur (and a trace of iron). In dealing with the soil as a culture medium, agronomists came to speak of a three-element fertilizer as being all-sufficient for crop growth though in practice the physiologist's three-salt mixture or its equivalent in complex organic materials was always used. Our experience with tobacco as well as the known chemical characteristics of the soil types under consideration would indicate that many of these soils are to be regarded as hardly more than somewhat impure sand culture media so that qualitatively at least their requirements as to a complete nutrient solution or salt mixture are fundamentally those applying to the pure sand cultures of the physiologist.

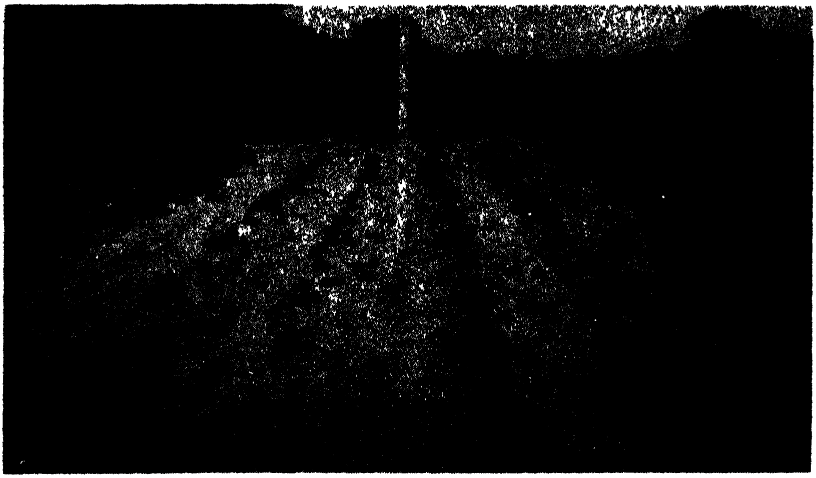

FIG. 1.—Tobacco in center plat received as fertilizer a mixture of nitrate of potash and ammonium phosphate. The plat to right received, in addition, calcium and magnesium. Photographed September 7.

TABLE 3.—*Growth of tobacco and absorption of macro elements as influenced by fertilization, Upper Marlboro, Maryland.*

Soil		Percentage composition					
		N	P_2O_5	K_2O	CaO	MgO	SO_3
Collington loamy sand		0.04	0.07	0.45	0.10	0.17	—
Fertilizer treatment	Total crop yield (leaf and stalk), lbs.	Quantity absorbed by the crop, lbs.					
Complete fertilizer*	907	17.6	5.3	32.8	24.4	5.1	2.6
Nitrogen omitted	405	*9.1*	3.3	18.6	7.2	2.9	—
Phosphorus omitted	166	5.6	*0.7*	6.7	3.2	1.2	0.6
Potassium omitted	404	11.0	2.5	*6.3*	8.5	2.9	—
Calcium omitted	349	12.5	1.7	11.4	*2.1*	2.8	—
Magnesium omitted	382	11.5	2.1	15.6	8.0	*1.1*	—
Complete fertilizer†	1,733	—	—	—	—	—	4.7
Sulfur omitted	1,350	—	—	—	—	—	3.1‡

N P_2O_5 K_2O CaO MgO SO_3 Cl B
*Complete fertilizer 1,000 lbs. of 6 — 6 — 6 — 8 — 2 — 2 — 2 — 0.1
†Complete fertilizer 1,000 lbs. of 3 — 8 — 5 — 8 — 2 — 2 — 2
‡Sulphur deficiency symptoms were apparent early in growing season but not at time of harvest.

However, it is now known that the plant physiologists have been in error also in supposing that a three-salt solution merely supplying nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, plus a trace of iron, is capable of meeting the nutrient requirements of plants. Such salt mixtures were effective only because of impurities

they contained. Manganese and boron in relatively minute quantity are now known to be essential for tobacco as well as other crop plants and boron deficiency has been shown to occur in tobacco under field conditions (4). In addition, by means of proper technic applied to solution cultures it has been shown recently that minute quantities of copper and zinc are essential for normal growth of tobacco (5).

As a part of our mineral nutrition research program considerable attention has been given to the rôle of the micro elements in the nutrition of micro-organisms (10). Since a relatively high degree of refinement in technic can be more readily attained in this case, it is of considerable interest to compare the results obtained in solution cultures with the fungus *Aspergillus niger* and with tobacco as a representative of green plants. So far, there has been no indication that boron is essential for Aspergillus and in this connection it may be recalled that in tobacco there is marked similarity in the symptoms of calcium deficiency and boron deficiency and since apparently calcium is not required by Aspergillus it need not be so surprising, perhaps, if boron also is not required. On the other hand, the evidence, though perhaps requiring confirmation, points to the conclusion that molybdenum and gallium are required by Aspergillus (11) and eventually they may be found to be essential for tobacco.

It is thought that the results of the studies briefly outlined above furnish a satisfactory background for a more effective physiological approach to the tobacco fertilizer problem, with special reference to the more tangible phases of the mode of action and the specific functions of the essential elements in the nutrition of the plant. In general, greenhouse cultures cannot be used, for the effects on leaf development of the artificial conditions involved in pot or solution cultures in the greenhouse are so profound that the specific effects of mineral nutrients are obscured or more or less obliterated. Our experience in working in the open indicates it is possible to locate areas of highly siliceous soils which are low enough in content of each of the six macro elements and at least some of the micro mineral elements concerned in nutrition to develop marked and specific deficiency effects in the plant which can be diagnosed with certainty (6). By use of sufficiently pure chemicals on such areas satisfactory material for many features of biochemical and physiological study can be grown and there is the great advantage that the results can be directly correlated with observed effects on the properties of the leaf which are of practical importance in commercial culture. This procedure of course does not lend itself to types of research requiring ultra refinement in purity of the culture medium, but such refinement is of no particular advantage in dealing with the present type of study.

Assuming reasonable uniformity of the soil as culture medium, the principal problem of control of conditions is presented, of course, by variation in the weather. In the nutrition problem under field conditions, especially with respect to mineral absorption and utilization, perhaps the most important weather variable is rainfall. It has been found possible, however, to control largely the water supply on a small scale by means of a water-proof canvas cover over the test plat, which is placed in position only during periods of rainfall, and

to apply, as needed, measured quantities of water by the usual overhead irrigation method. In this way the relation of the water supply to selective absorption of nutrients and their effects on processes of metabolism and leaf growth and development can be studied in detail. It was found, for example, that in comparison with sustained conditions of drought, an approximately optimum moisture supply which doubled leaf area and caused appreciable decrease in weight per unit of area, gave an increased absorption of nitrogen of only 40% but increased potash absorption 160% and that of sulfur (SO_3) nearly 180% (Table 4). In the study of the physiological processes in relation to mineral nutrition our experience has been that ordinarily trends are best developed by making a series of observations at intervals through the growing period. Naturally, repetition for two or more seasons will afford a truer picture of the interrelation of mineral nutrition and metabolism with respect to possible modifying influences of the weather factors other than rainfall. As already stated, the latter can be directly controlled.

Brief reference may now be made to results obtainable in applying plant physiological methods by means of the procedure which has been outlined. The data presented were obtained on Collington loamy sand and sandy loam soils at Upper Marlboro, Maryland. For success of the plan it is essential, of course, that satisfactory absorption of the several essential elements be obtainable. Of special interest in this connection are the results obtained in a comprehensive experiment with potassium applied as sulfate at eight different rates (8) in which a remarkably close approach to a smooth absorption curve was obtained (Fig. 2). In somewhat less extensive tests with calcium and with nitrogen, almost equally satisfactory absorption data were secured. In each instance, the absorption increments for the lower rates of application rather closely approach a linear series, but at higher rates of application the absorption increments fall off rapidly. Observations made separately on leaf and stalk in the case of nitrogen indicate a rather definitely linear relation in the absorption increments for the stalk.

Up to the present, principal attention has been given to the quantity of the nitrogen supply, in the form of nitrate, in its relation to metabolism and other internal processes as associated with growth and development of the plant, and the physical and chemical characteristics of the cured leaf. The rates of nitrogen application were 20, 40, and 80 pounds per acre, with a control treatment, and 60 pounds of phosphoric acid and 40 pounds of potash were uniformly applied, along with adequate provision for calcium, magnesium, and sulfur. The yield data for a 10-year period conformed reasonably well with the requirements of the Mitscherlich equation, but only when the proportionality factor was given a new numerical value to fit the conditions of the test (Fig. 3, A). Throughout the principal growth period there was an increased content of protein, nicotine, and other nitrogen fractions in the leaf as a result of an increase in the nitrogen supply. This increase in assimilated nitrogen was accompanied by a uniformly high water content in the leaf and a decided decrease in content of starch. The consistency of all the results, as obtained at

TABLE 4.—*Effects of water supply on absorption of nutrients, growth, and leaf development in tobacco, Upper Marlboro, Maryland.**

Treatment	Average moisture content of soil, %	Yield of leaf per acre, lbs.	Pounds of plant food recovered per acre (leaf and stalk)							Area of leaves per plant, sq. ft.	Weight of leaf per sq. ft., grams
			Total ash	N	P_2O_5	K_2O	CaO	MgO	SO_3		
No water applied	3.8	530	102	27.7	4.3	39.4	23.0	6.0	3.3	7.75	5.28
½ in. water twice weekly	8.7	1,034	241	38.8	10.5	102.6	43 5	10.4	9.2	15.71	5.08
Natural rainfall	6.7	868	198	42.3	8.9	90.6	31.0	10.2	7.0	14.29	4.89

*Collington sandy loam. Fertilizer per acre 30 pounds N; 60 pounds P_2O_5; 90 pounds K_2O; 84 pounds CaO; 209 pounds SO_3.

frequent intervals during the growth period, is taken to indicate the soundness of the procedure followed and the dependability of the sampling (Fig. 3, B).

In association with the above-mentioned effects of nitrogen supply on internal conditions, the maximum growth rate as measured by increase in height and date of flowering, as well as the narrowest ratio of leaf to stalk and of lamina to midrib in the individual leaf, were

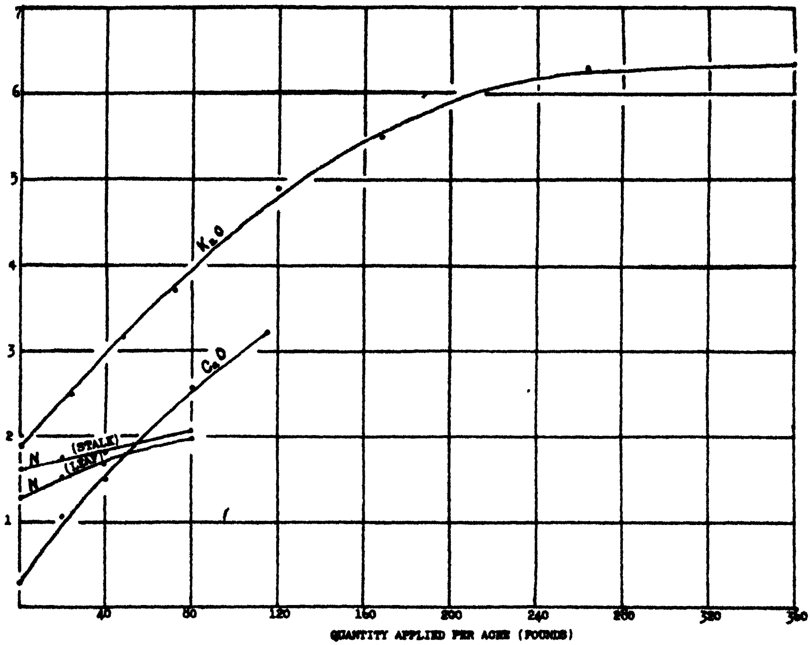

FIG. 2.—Absorption curves, showing increase in percentage content of potash and calcium (CaO) in the leaf and of nitrogen in leaf and stalk, as the rate of application of these elements is increased. The absorption values show in each case a very close approach to a smooth curve, the values for the leaf at lower rates of fertilization tending to form series which are almost linear while at the heavier rates the curves rapidly flatten. Nitrogen absorption values for the stalk form a more definitely linear series.

attained with a moderate nitrogen supply (Table 5). The slow growth caused by nitrogen deficiency resulted ultimately in an increased number of leaves per plant. A high nitrogen supply produced the broadest, largest leaves in association with the high turgor which was uniformly maintained, while, conversely, these leaves were thinnest and lightest in weight per unit of area. The combustibility of the leaf was lowered, presumably because of the increase in protein content.

Results obtained with the cured leaf confirm and amplify the data on the growing plant as indicative of the profound effect of the nitrogen supply on the chemical and physical properties of the leaf (Table 5). In fact, the experimental data as a whole obtained with

Maryland tobacco grown at different levels of nitrogen nutrition furnish a very satisfactory background for the assumption that, with other conditions equal, it is possible by greatly varying the nitrogen supply to change fundamentally the type or class of tobacco produced.

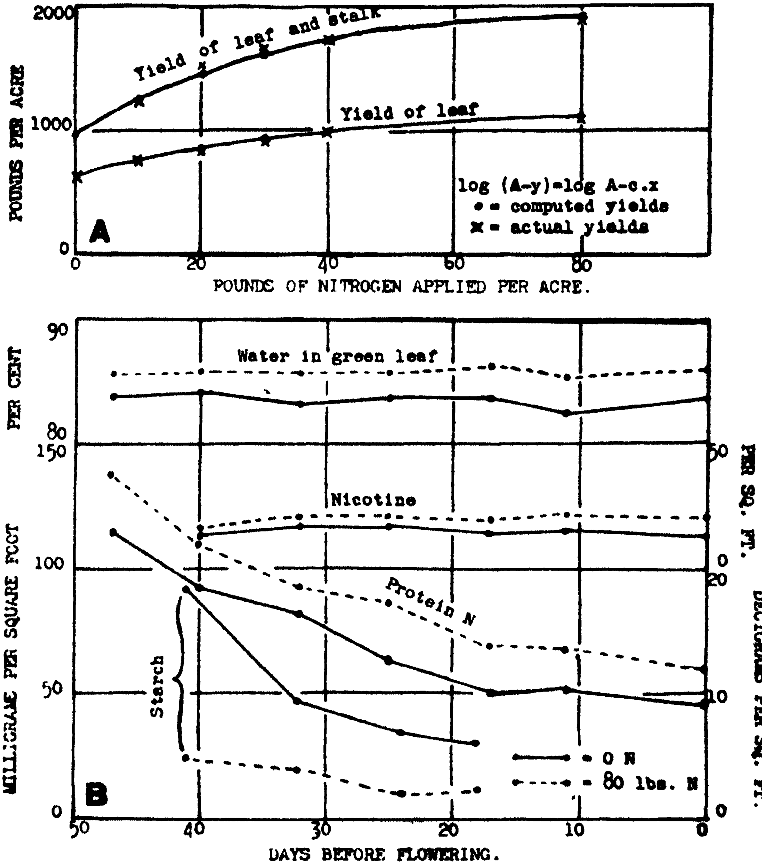

FIG. 3.—Effects of an increased supply of nitrogen on (A) 10-year average yield of leaf and of leaf and stalk combined in relation to the Mitscherlich equation; and (B) content of the growing leaf in protein, nicotine, starch, and water through a period of 46 days preceding the flowering stage. The Mitscherlich equation is applicable only if the numerical value of the proportionality factor (C) is suitably increased. The biochemical data are notably consistent throughout.

Reference is made to the flue-cured and Maryland cigarette types, on the one hand, and to the cigar wrapper leaf, on the other hand. The contrast between the flue-cured and cigar wrapper types in properties of commercial importance is as wide, perhaps, as that between any commercial types produced. The Maryland type is somewhat intermediate as a whole, but in many respects is more nearly like the flue-cured leaf. Much the same type of soil is used in growing the three

Table 5.—*Relation of nitrogen supply to growth and development of the tobacco plant, the physical and chemical properties of its leaf, and the commercial type of leaf tobacco produced.*

Measurement	Type of Leaf				
	Flue-cured cigarette leaf with 25–30 lbs. of N per acre	Maryland cigarette leaf, with			Cigar binder and wrapper leaf with 200 lbs. of N per acre
		No treatment	20 lbs. of N per acre	80 lbs. of N per acre	
Growth, Development, and Physical Properties					
Percentage of plants flowering in 70 days	—	38	82.7	81.9	—
Average height at end of 42 days, in.	—	21.0	43.9	44.7	—
Percentages of leaf and stalk, respectively	—	65; 35	59; 41	60; 40	—
Percentage of midrib in leaf	—	27.1	29.3	27.8	—
Average number of leaves per plant	—	34.6	27.2	28.0	—
Average area of leaves, sq. in.	—	96.7	146.0	197.9	—
Ratio of length to width of leaf	—	2.17	2.05	1.88	—
Dry weight of mature leaf per square foot, grams	—	6.05	5.48	4.60	—
Apparent average thickness of leaf, microns	—	500	390	280	—
Combustibility, duration of glow, seconds	—	24.9	9.1	6.0	—
Av. wt. of cured leaf per sq. ft., grams	7.9	4.8	4.3	3.6	2.75–4
Color of cured leaf	Lemon to orange	Yellowish red to reddish brown			Light brown
Chemical Characteristics of Cured Leaf, %					
Protein	6.38	7.50	9.06	11.50	8.23
Amides and amino acids	2.91	1.97	2.47	3.12	8.71
Nicotine	2.25	0.63	0.73	1.46	2.92
Ammonia	0.01	0.08	0.06	0.19	0.55
Nitrate (NO_3)	0.03	0.08	0.08	0.50	3.19
Total N	2.04	1.81	2.18	3.06	4.84
Starch	3.02	4.34	3.34	1.52	0.0
Sugar	10.48	1.80	1.60	0.79	0.21
Cellulose (fiber)	10.80	16.07	17.20	16.60	13.28
Pectin	12.21	16.17	16.71	15.14	9.77
Citric and malic acids	5.11	4.33	5.53	8.68	9.51
Ash	16.00	14.70	12.88	14.96	20.01
Total assimilated nitrogen fraction	11.55	10.18	12.32	16.27	20.41
Starch and sugar	13.50	6.14	4.94	2.31	0.21
Cellulose and pectin	23.01	32.24	33.91	31.74	23.05
Total carbohydrate	36.51	38.38	38.85	34.05	23.26

types of leaf, but the quantity of nitrogen employed for the cigar leaf is about eight times that used for the cigarette types.

Comparison of the Maryland leaf grown experimentally at three different levels of nitrogen fertilization with standard samples of flue-cured and cigar leaf types shows unmistakably in numerous details of chemical as well as physical characteristics a definite trend away from the cigarette type toward the cigar type as the rate of nitrogen fertilization is increased (Table 5). Certain of these contrasts in properties between the different tobaccos, including differences in color, are accentuated by differences in methods of curing. The flue-cured type is rather rapidly dried or cured with artificial heat, while the Maryland and cigar types are subjected to a slow process of curing under natural conditions. Under the latter conditions, there is more extensive hydrolysis of protein and starch and sugar are mostly consumed in respiration. In flue curing, starch is mostly converted into sugar, but consumption of the latter by respiration is relatively slight. As the nitrogen supply is increased, the color tends to change from yellow to brown and the leaf becomes thinner and lighter in weight. There is a definite progressive increase in the several components of the nitrogen fraction and in organic acids and a corresponding decrease in starch and sugar, but the non-plastic carbohydrate is not much affected.

Briefly, the cigar type is characterized by a very high nitrogen fraction and low total carbohydrate fraction, while the reverse relation applies to the two cigarette types. The essential characteristic of the flue-cured leaf is the high sugar content, which frequently runs 20% or more of the dry weight. The Maryland type differs from both the flue-cured and cigar types in its exceptionally high content of non-plastic carbohydrate, cellulose, and pectin. This, however, is primarily a varietal characteristic to be ascribed to heredity. These differences in chemical composition greatly affect not only the physical properties already mentioned, but also others not readily measured, including the so-called body, texture, and elasticity.

Brief reference may be made, finally, to content of nicotine which is the characteristic alkaloid of tobacco. Though increased nitrogen supply tends to increase the nicotine content, the major factors are heredity and the cultural operation known as topping, or disbudding the plant. Removing the upper portion of the plant ordinarily causes a subsequent rapid increase in content of nicotine in the remaining leaves, low and early topping being especially effective (Fig. 4). In a comparative study of high-nicotine and low-nicotine strains of tobacco no correlation was found between protein content and nicotine content during the growing and developmental period. The dark fire-cured and dark air-cured tobaccos are highest in nicotine of any produced in this country, mainly because of the low, early topping practiced, while the Maryland is lowest in nicotine through the combined effects of heredity and high, very late topping.

SUMMARY

In connection with fertilizer experiments conducted in cooperation with several of the tobacco-growing states, the necessity for developing a physiological approach to the tobacco fertilizer problem, more particularly on light sandy and sandy loam soils, was well demonstrated in certain tests with potash salts at the Oxford, N. C., tobacco station which resulted in the discovery in 1923 of magnesium deficiency in these soils, accompanied by characteristic deficiency symptoms in the crop grown on them.

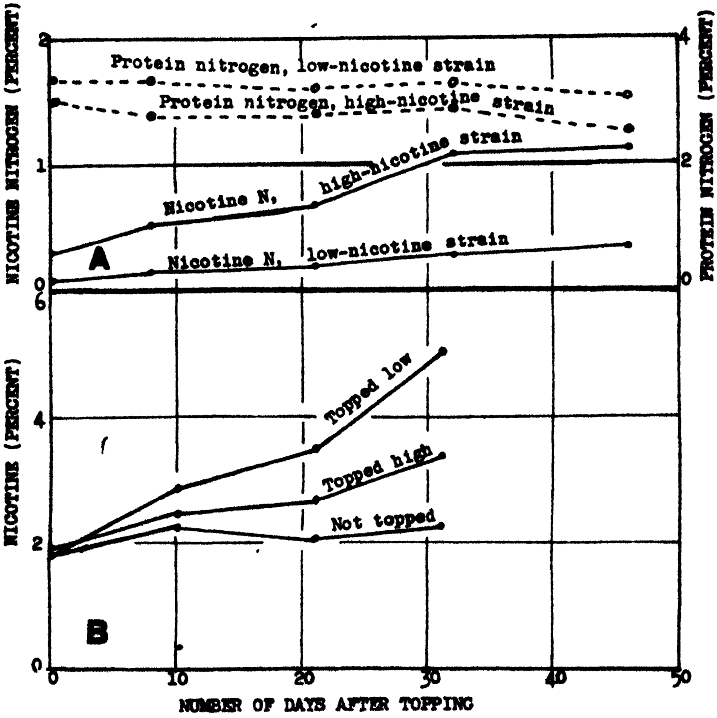

FIG. 4.—A, nicotine content of high-nicotine and low-nicotine strains of the Cuban variety through a period of 47 days after topping. The latter strain failed to accumulate nicotine rapidly in the leaves as normally occurs with ordinary varieties after topping, even though this strain maintained a higher protein content than the high-nicotine strain. B, effect of high topping and low topping on accumulation of nicotine in the leaf, the latter causing a very marked increase in content of alkaloid and emphasizing the potency of this factor.

Chemical analysis of the soils in question and of the tobacco they produce indicates that they are quite as likely to be deficient in calcium, magnesium, and sulfur as in nitrogen, phosphorus, and potassium. Field tests have shown that this is actually the case. In specific cases soil deficiency in all of these six elements has been

demonstrated by (a) marked depression in yield obtained, (b) occurrence in the crop of distinctive deficiency symptoms, and (c) abnormally low content in the crop of the particular element withheld from the fertilizer.

The above-mentioned soils are to be regarded simply as somewhat impure sand culture media and it is not logical, as has been very commonly done in the past, to apply to these soils salts or other substances containing two or more essential elements, without any compensating treatment, and attempt to evaluate the results obtained with plants in terms of only one of the constituent elements.

With soils properly selected with respect to the above-mentioned criteria of mineral deficiency and with the precaution of varying the supply of only a single essential element, excellent data have been obtained on absorption by the plant in relation to increased supply of this element.

Utilizing this plan of conducting "field sand cultures", consistent and significant results have been obtained in extensive physiological studies of effect of the nitrogen supply on growth and development phenomena, metabolism, and other internal relations, and on the chemical and physical properties of the cured tobacco leaf. This appears to furnish a reasonably adequate procedure for study of the more tangible aspects of the mode of action of the essential elements in plant growth and associated phenomena.

LITERATURE CITED

1. GARNER, W. W., MCMURTREY, J. E., JR., BACON, C. W., and MOSS, E. G. Sand drown, a chlorosis of tobacco due to magnesium deficiency, and the relation of sulphates and chlorides of potassium to the disease. Jour. Agr. Res., 23:27 40. 1923.
2. ——————, ——————, BOWLING, J. D., JR., and MOSS, E. G. Magnesium and calcium requirements of the tobacco crop. Jour. Agr. Res., 40:145–168. 1930.
3. ——————, ——————, ——————, ——————. Rôle of chlorine in nutrition and growth of the tobacco plant and its effect on the quality of the cured leaf. Jour. Agr. Res., 40:627–648. 1930.
4. MCMURTREY, J. E. Boron deficiency in tobacco under field conditions. Jour. Amer. Soc. Agron., 27:271–273. 1935.
5. —————— and ROBINSON, W. O. Neglected soil constituents that affect plant and animal development. U. S. D. A. Yearbook, 1938:807–829. 1938.
6. ——————. Symptoms on field-grown tobacco characteristic of the deficient supply of each of several essential chemical elements. U. S. D. A. Tech. Bul. 612. 1938.
7. MORGAN, M. F. The soils of Connecticut. Conn. Agr. Exp. Sta. Bul. 320: 825–911. 1930.
8. OJIMA, USHIRO. The growth and the rate of the nutritive absorption of tobacco. Centr. Res. Inst. Gov. Monopoly Bu. [Japan] Sci. Papers, No. 45. 1933.
9. ROBINSON, W. O., STEINKOENIG, L. A., and FRY, WILLIAM H. Variation in the chemical composition of soils. U .S. D. A. Bul. 551. 1917.
10. STEINBERG, ROBERT A. Relation of accessory growth substances to heavy metals, including molybdenum, in the nutrition of *Aspergillus niger*. Jour. Agr. Res., 52:439–448. 1936.
11. ——————. The essentiality of gallium to growth and reproduction of *Aspergillus niger*. Jour. Agr. Res. 57:569–574. 1938.

NOTE

HOW SHOULD VARIETIES OF ANNUAL SELF-FERTILIZED CROPS BE PERPETUATED?[1]

THERE are in use today fundamentally different methods for the perpetuation of varieties of annual self-fertilized crops such as wheat. Since the procedure is essentially simple, the existence of widely different treatments to attain the same practical ends invites scrutiny. On the one hand there is the selection of an individual plant as the sole representative of a variety, and on the other the insistence on taking a population-size random sample for this purpose An examination of the situation should prove interesting.

A variety of a self-fertilized cereal crop is a population of individuals which resemble one another closely in easily observable morphological and qualitative features. The interpretation of this close resemblance varies from the American concept, which separates varieties on the basis of fairly small differences in glume shape, awn length, beak length, spike shape, and so on, to the European concept, which considers such American varieties as Marquis, Kitchener, Red Fife, and Early Red Fife as forms within the same variety. For the purpose of the present discussion, the term "variety" will be considered according to common American usage.

Most varieties in common use are not "pure lines". According to Mendelian principles of inheritance, the progeny of a cross between two plants of a normally self-fertilized species, if continuously self-fertilized for about 20 years without interference from natural crossing or mutation, will consist almost entirely of homozygous plants. Usually a variety of a self-fertilized crop is the increased progeny of an F_5 or F_6 plant. Sometimes a breeder re-selects in F_9 or F_{10}. In either case the increased progeny is actually far from homozygous for many genes governing characters in which uniformity can only be grossly estimated by existing tests. This point has been discussed rather fully by the writer.[2]

The individual plant which is increased and its progeny tested and distributed as a new variety probably would be heterozygous for many genes concerned with milling and baking attributes and other quantitative characters. After this variety has been in use for 10 or 15 years, nearly every plant which has not been affected by natural crossing or mutation would be a pure line. The population would then contain numerous pure lines differing from one another with respect to the above-mentioned genes. In any event the population will be a mixture of biotypes and these constitute the variety which has proved its value to farmers as attested by the extent of its use.

On the supposition that it is better to have a pure line variety, a single plant is removed from the variety in question. This single plant

[1]Written at the suggestion of Prof. E. B. Babcock, Head of Genetics Division, University of California, Berkeley, Calif.

[2]HARRINGTON, J. B. Purity concepts with respect to crop varieties. Sci. Agr., 11:411–417. 1931.
Problems in the development of elite stocks of disease resistant varieties of crops. Ann. Rpt. Can. Seed Growers' Assoc., 59–71. 1937.

may have a gene complex, which gives it the actual average expression of all the characters of the variety, and in this way it is a true and accurate representative of the variety. The chance, however, of any given selection being this particular ideal plant is extremely remote in a crop with the character complexity of wheat, for example. The chances are great, on the other hand, that the single plant selection, while morphologically appearing to represent the variety closely, will be either better or worse than the variety in grain yield, protein content, loaf volume, drought resistance, and various other economically important characters.

Now, if the purpose of making the selection is to improve the variety, a perfectly legitimate breeding problem, it is obvious that *many* selections should be taken, progenies grown, exhaustive tests made, and eventually one of the selections chosen on the basis of these tests to supersede the parent variety.

On the other hand, if the purpose of making the selection is to maintain the existing stock of the variety, also a perfectly legitimate procedure, it is equally obvious that *many* plants will have to be taken. But in this case it is vitally important to take a random sample of the population which constitutes the variety and have that sample large enough to represent the variety accurately. About eight years ago, a group of plant breeders, when confronted with setting an arbitrary minimum size of random sample that would be statistically satisfactory to represent a variety, ruled that such a sample should contain at least 50 plants.

Previous to this time, a large seed growers' association had run into difficulties because it had single plant selection (or pure lining) as one of its methods of producing pure seed of a variety. A number of its members, working with the famous wheat variety Marquis, each selected individual plants, grew their progenies, and selected the best looking one to be his future stock of the variety. Thus arose many strains of Marquis, some of which differed noticeably from the others even in minor morphologic features.[3] After a review of the situation, the association barred "pure lining" as a method of producing a pure stock of a variety on the fundamental grounds that "pure lining" is not a method of maintaining a variety but of improving a variety and therefore was definitely the plant breeder's business.

Then, in order to protect the identity of a variety and at the same time keep it from deteriorating through mixture or disease, the association, in drawing up its new regulations for producing elite stock seed, insisted not only on a minimum random sample of 40 plants, but upon two successive years of progeny tests for the purpose of noting and eliminating any progenies distinctly different in appearance from the norm or average.

The plant breeder often takes individual plant selections from a variety which has become mixed or from a new variety which was bulked in F_4 or F_5. In the latter case, the purpose of the selecting is to improve on the variety, and the selections may show significant

[3]HARRINGTON, J. B. A comparative study of strains of Marquis wheat. Sci. Agr., 8:77–104. 1927. Also unpublished later work of the writer.

differences in many respects. Recent examples are the selections made in Apex wheat at the University of Saskatchewan and Renown wheat at the Dominion Rust Research Laboratory in western Canada.

At many institutions a high degree of homozygosity is maintained in variety stocks for genetic research, through the selection each year, or every few years, of a single apparently representative plant to carry the stock along. This practice is sound, if the selected plant is protected from natural crossing. But it must be kept in mind that the results of the research apply strictly to the stock used and only approximately to the variety from which the stock was derived. It may be noted further that the desire for genetic purity in such a stock is in no way indicative of a need for such a high degree of homozygosity in a commercial variety.

Although seed growers' organizations appear to aspire to higher and higher purity in their cereal stocks, it cannot be said that in practice they seek genetic purity or have need of it. It has never been proved that a homozygous stock in a normally self-fertilized species is superior to one slightly less homozygous but otherwise similar. And there are many people who are against having extremely high purity in such material. One of their arguments is that heterosis is reduced to nothing as compared with something; another one is that a mixture of biotypes should be more adaptable than a single pure line to the various environments encountered in any given location; and a third is that since complete homozygosity is almost nonexistent in nature, it is working against nature to render a variety homozygous.—J. B. HARRINGTON, *University of Saskatchewan, Saskatoon, Canada.*

AGRONOMIC AFFAIRS

DOCTOR J. G. LIPMAN

DOCTOR J. G. LIPMAN, Dean of the New Jersey College of Agriculture and Director of the New Jersey Agricultural Experiment Station, died on Wednesday, April 19, following a brief illness.

Doctor Lipman was a charter member of the American Society of Agronomy and until his death was actively identified with the Society in various capacities. He was elected a Fellow of the Society in 1926 and in 1927 served as a member of the American Organizing Committee for the First International Congress of Soil Science which was held in Washington, D. C., in June of that year. He was later elected President of the Executive Committee of the Congress. At the time of his death he was lending very substantial aid in perfecting arrangements for the meeting of the Third Commission of the International Society of Soil Science which is to meet in New Brunswick in August.

A more complete account of Doctor Lipman's life and contributions to agronomy will appear in a later issue of this JOURNAL.

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TILLERING ABILITY OF SORGHUM VARIETIES[1]

J. B. SIEGLINGER AND J. H. MARTIN[2]

CULTIVATED varieties of sorghum differ widely in the number of tillers or "suckers" normally produced by a plant. Within a variety, tillering is influenced by environmental factors, such as plant spacing, soil moisture, soil fertility, temperature, growing period, date of planting, and stage at which the soil is thrown into lister furrows covering the bases of the plants. All sorghum plants normally bear a bud at each of the 8 to 10 underground nodes in the crown Each of these buds might eventually produce a tiller under proper stimuli and suitable growing conditions, but rarely do all tillers produce buds in a single growing season.

The ability of a sorghum plant to produce more than one stalk has been recognized by botanists and sorghum growers since the species was first described. Varietal differences in tillering have been noted by many agronomists, some of whom, including Ball and Rothgeb (1),[3] Sieglinger (9), Karper, *et al* (5), and Quinby, *et al* (8), have presented data on the relative tillering of a considerable number of varieties. The effect of spacing on tillering in milo was shown by Hastings (3).

The ability or tendency to produce more than one stalk often is of practical importance in enabling the plant to take advantage of surplus space, moisture, and plant food. Agronomists differ, however, in opinion regarding the general desirability of tillering in sorghums. Studies by Sieglinger (10), Karper (4), Martin, *et al.* (7), and Karper, *et al.* (5) to determine the best spacing for sorghum plants have indicated that the optimum spacing depends upon the tillering habit of the variety and that varieties which tiller poorly should be planted relatively thick. With the recognition of this relationship, a study of varietal differences in the tillering ability of sorghums was begun in 1930 at the Southern Great Plains Field Station, Woodward, Okla. A varying but representative collection of all important sorghum groups and including 150 or more varieties has been grown in single rows at that station for several years for observation and for the maintenance of breeding stocks. In order to facilitate the study of

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication January 20, 1939.
[2]Agronomist and senior agronomist, respectively.
[3]Numbers in parenthesis refer to "Literature Cited", p. 488.

tillering behavior, half of each row was thinned to a spacing of about 3 feet between plants and the remainder, where possible, to a plant spacing of 6 inches. Stalk and plant counts recorded on each half of the row furnish the basis for the data presented here.

MATERIALS, METHODS, AND SEASONAL CONDITIONS

The miscellaneous sorghum varietal nursery at Woodward consisted of single 132-foot rows, 3½ feet apart, of standard varieties and many newly developed or introduced varieties of both grain and forage types. The varieties and selections were grouped in the nursery according to their agronomic classification. All varieties were planted on a single day, between June 11 and June 16 each year, and the plants emerged four to six days later. The planting was always thicker than necessary to produce the desired stand under usual conditions. Thinning to the desired spacing was done by hand during July when the plants were 3 to 5 inches tall. Half of each row (66 feet) was thinned to approximately one plant each 36 inches in the row, while in the remainder of the row the plants were spaced as nearly as possible to one plant every 6 inches. It was difficult to approximate a 6-inch spacing because of differences in germination, seedling survival, and seed size, and an average actual spacing of about 7.4 inches was secured. The number of plants in each half row was determined soon after thinning and the stalks were counted at the end of the growing season. A tiller over 6 inches or more in height was counted as a stalk, but shorter tillers were disregarded. In favorable seasons a high percentage of all stalks produced heads and grain, but in severe years even the main stalks of many varieties did not produce heads.

There were wide varietal variations in tillering in different years in both thin and thick spacings. A brief statement of the chief seasonal weather conditions influencing sorghum growth therefore is presented. In 1930 a drought extended from the second week of June to the third week of August, but tillering and vegetative growth were stimulated by moisture that became available in late August, September, and early October.

The growing season of 1931 started favorably, but hot, dry periods followed at intervals during the summer months. Intermittent rains caused some varieties of sorghum to develop numerous tillers in the thin spacing. Sorghum yields were near the average. The 1932 season was characterized by excessive precipitation in June and no effective rain in July, but a rainy period in August resulted in yields of sorghums above average.

The sorghum nursery was not planted in 1933 because a drought from the first of May until the middle of July caused planting to be postponed until too late. The season of 1934 was hot and dry from the middle of June to the middle of August and sorghum yields were very low. Certain early-maturing varieties only were planted. In 1935 precipitation was low in the summer months and sorghum yields were only about 50% of the average. The 1936 season was the worst in the history of the station (23 years). No effective rain occurred from the first week of June until the first week of September. High temperatures and low humidity prevailed throughout the summer and sorghum yields were practically zero. In 1937 conditions were rather favorable at planting time but drought and high temperatures followed. Rains came in late August and September. Fair yields of most varieties were obtained.

RESULTS OBTAINED

The annual and average number of stalks per plant of the varieties in thick and thin spacings is shown in Table 1. The average number of tillers, or suckers, per plant may be computed by subtracting one from the number of stalks per plant. A total of 86 varieties and strains was grown and data recorded in each of six years and four or five years' data from 19 additional varieties also are included. Some of these 19 varieties were grown in other years, but owing to poor stands and the consequent irregular tillering the data for these years are not shown. Averages are shown for the varieties grown less than six years in order to permit general comparisons despite the fact that the data are not fully comparable. Seasonal variations in the rank of the varieties were common, but in most cases the average relative tillering of the varieties was of similar order whether 4, 5, or 6 years' data were included. Only a few early varieties were grown in 1934 and the data for that year are not included in the varietal averages except in the case of a few varieties not grown in 1930 and 1931.

The average space per plant in the thick spacing (Table 1) is about 7.4 inches The average thin spacing attained was sufficiently close to the 36 inches desired, except in Blackhull kaoliang and Freed, so that the relative number of stalks per plant shown is reasonably accurate in most varieties Varieties that tillered heavily were affected but slightly by variations from the 36-inch spacing.

The range of the varieties in the thick spacing, with average extreme distances between plants of 5.7 to 10.3 inches, probably accounts to a considerable extent for the variation in tillering that does not correspond to the rank of the varieties in tillering in the thin spacing.

The six seasons differed somewhat in the average number of tillers produced by the 79 varieties in the recognized groups grown each of the six years In average annual number of tillers in the thin spacing the seasons ranked in descending order as follows: 1932, 1937, 1936, 1931, 1935, and 1930. The various groups followed the general trend only in part. It will be observed that most varieties produced at least a few tillers regardless of spacing or season, although some did not tiller even in the thin spacing in certain years. Extremes in tillering in the thin spacing ranged from none (one stalk per plant) for several varieties in various seasons to 5.8 (6.8 stalks per plant) in feterita (C. I. 693) in 1936, with a spacing of 39.6 inches.

The average number of stalks per plant in the various sorghum groups given in Table 1 is shown more effectively in Fig. 1.

The hegari group, consisting of only two varieties grown five years, showed the highest tillering capacity, having produced 3.23 tillers (4.23 stalks) per plant in the thin spacing and 1.03 tillers per plant in the thick spacing. Durras showed the least tendency to tiller and the kafirs tillered only slightly more. The number of tillers per plant in the thick spacing followed the same order by groups as in the thin spacing except in the case of sorgo, in which tillering in the thick spacing was low proportionally. This discrepancy apparently

TABLE 1.—*Annual and average number of stalks per plant and average plant spacing of 105 sorghum varieties grown at Woodward, Okla., in thick and thin spacings.*

Variety	C. I.[1] No.	Number of stalks per plant																Average plant spacing, inches	
		1930		1931		1932		1934		1935		1936		1937		Six-year average			
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Milo																			
Dwarf Yellow	332	1.32	3.57	1.40	4.59	1.40	3.61	—	—	2.41	4.24	1.48	1.30	1.46	2.64	1.59	3.33	7.9	36.1
Dwarf Yellow	359	1.35	2.78	1.58	4.13	1.75	4.18	—	—	1.87	3.09	1.35	1.35	1.58	3.09	1.60	3.10	7.9	35.2
Double Dwarf	868	1.44	3.36	1.39	4.35	2.06	3.35	—	—	2.11	3.32	1.38	1.61	1.58	2.00	1.66	3.00	7.5	35.2
Dwarf White	627	1.13	2.71	1.73	4.29	1.50	4.18	—	—	1.90	3.55	1.25	1.77	1.55	2.81	1.51	3.22	7.0	36.1
Early White	480	1.09	1.57	1.46	3.13	1.64	3.65	1.16	1.73	1.38	3.41	1.20	1.59	1.17	2.64	1.32	2.67	7.8	35.5
Standard Yellow	234	1.23	1.95	1.27	3.44	1.37	3.62	—	—	1.29	2.64	1.29	1.59	1.46	3.23	1.32	2.75	7.7	34.8
Standard White	352	1.16	2.20	1.48	3.57	1.24	3.55	—	—	1.58	3.05	1.22	1.67	1.47	3.09	1.36	2.86	7.6	35.8
Sooner	917	1.13	2.55	1.36	3.08	1.34	3.86	1.09	2.17	1.25	2.55	1.52	2.52	1.49	3.05	1.36	2.94	8.4	36.1
Sooner (Chillicothe) F. C. 8975[2]	—	—	—	—	—	—	—	1.63	2.91	1.60	3.87	1.21	2.09	1.35	3.62	1.45[3]	3.12[3]	6.9	35.6
Sooner (Lubbock)	—	—	—	—	—	—	—	1.11	2.47	1.50	3.57	1.56	2.82	1.35	3.23	1.38[3]	3.02[3]	7.4	37.1
480 x 332-16	962	1.44	2.67	1.30	2.65	1.29	2.91	1.41	2.52	1.14	2.52	1.56	2.05	1.80	4.23	1.42	2.84	7.3	35.7
Day	959	—	—	—	—	1.55	2.78	1.12	1.46	1.46	1.60	1.57	2.23	1.34	1.82	1.41[4]	1.98[4]	8.7	33.3
Pygmy	1010	—	—	—	—	1.46	2.50	1.35	2.79	1.18	1.83	1.52	3.00	1.21	1.41	1.34[4]	2.31[4]	8.9	33.9
Average (9 varieties)	—	1.25	2.60	1.44	3.69	1.51	3.66	—	—	1.66	3.15	1.36	1.72	1.51	2.98	1.46	2.97	7.7	35.6
Milo-kafir Derivatives																			
Wheatland	918	1.08	1.55	1.62	2.55	1.37	3.00	1.21	2.26	1.00	2.71	1.16	1.76	1.36	2.10	1.27	2.28	7.4	36.9
Wheatland backcross	—	—	—	1.74	3.09	1.56	3.05	—	—	1.17	3.17	1.58	3.48	2.53	3.73	1.72[4]	3.30[4]	8.1	36.0
Smith milo x kafir	808	1.03	1.10	1.06	1.63	1.10	1.50	1.00	1.00	1.01	1.00	1.03	1.25	1.10	1.05	1.06	1.26	7.9	35.0
Fargo	809	1.04	1.05	1.17	2.07	1.49	2.36	—	—	1.16	1.32	1.02	1.04	1.11	1.14	1.17	1.50	7.8	34.9
Desert maize	—	1.20	1.50	1.67	2.87	1.47	2.59	—	—	1.83	1.83	1.17	1.05	1.39	2.18	1.46	2.00	9.5	35.2
Manko	—	1.00	1.10	1.18	1.96	1.13	3.71	—	—	1.05	1.25	1.08	1.09	1.26	1.73	1.12	1.81	7.3	35.8
Kalo	902	1.06	1.15	1.18	1.88	1.14	2.73	—	—	1.16	2.33	1.01	1.14	1.27	2.18	1.14	1.90	6.4	35.9
Early kalo	1009	—	—	—	—	—	—	1.41	3.08	1.15	2.04	1.00	1.00	1.21	2.19	1.19[3]	2.08[3]	6.3	34.6
Custer	919	1.04	1.09	1.00	1.04	1.20	1.82	—	—	1.04	1.36	1.01	1.55	1.19	1.36	1.08	1.37	6.5	36.1
Beaver	871	1.02	1.21	1.15	1.88	1.19	2.26	1.16	2.08	1.14	1.57	1.00	1.18	1.46	2.05	1.16	1.69	7.0	34.2
A x 332-6	961	1.04	1.00	1.13	2.09	1.24	1.77	1.22	1.11	1.04	2.17	1.06	1.48	1.28	1.61	1.13	1.69	6.5	35.5
A x 332-31-79	960	1.02	1.24	1.33	1.88	1.05	2.36	1.06	1.38	1.05	1.63	1.23	1.23	1.10	1.41	1.13	1.63	7.5	35.1
Kafir x milo-8-2-6	1090	1.02	1.13	1.03	1.04	1.01	1.70	1.44	1.58	1.04	1.16	1.15	1.30	1.26	1.14	1.09	1.25	8.1	34.0
Kafir x milo-38-1-2-1	970	1.02	1.17	1.15	1.67	1.14	2.23	1.33	2.08	1.00	1.64	1.14	1.91	1.19	1.36	1.11	1.66	7.3	35.2
Bishop	814	1.04	2.29	1.82	2.24	1.13	3.17	—	—	1.39	2.48	2.02	4.14	1.68	3.76	1.51	3.01	8.0	35.3
Average (13 varieties)	—	1.05	1.28	1.27	1.91	1.20	2.40	—	—	1.15	1.73	1.16	1.55	1.28	1.77	1.19	1.77	7.5	35.3

Kafir																			
Blackhull	71	1.04	1.19	1.00	1.25	1.03	2.50	—	—	1.01	1.28	1.17	1.82	1.01	1.41	1.04	1.58	5.8	35.1
Blackhull	204	1.00	1.14	1.02	1.17	1.05	2.76	—	—	1.05	1.05	1.14	1.96	1.59	1.32	1.14	1.57	7.7	36.1
Sharon Blackhull	813	1.02	1.29	1.02	1.04	1.04	2.62	—	—	1.00	1.14	1.09	1.95	1.01	1.73	1.03	1.63	5.8	37.3
Texas Blackhull	865	1.00	1.00	1.04	1.00	1.01	2.62	—	—	1.03	1.00	1.15	1.70	1.24	1.43	1.08	1.46	7.1	36.4
Western Blackhull	906	1.01	1.19	1.06	1.04	1.01	2.18	—	—	1.00	1.14	1.07	1.45	1.53	1.25	1.11	1.38	8.5	36.6
Santa Fe No. 1	—	1.02	1.33	1.02	1.00	1.03	2.09	—	—	1.05	1.09	1.18	2.05	1.01	1.50	1.05	1.51	6.1	36.3
Reed	628	1.02	1.38	1.05	1.48	1.02	2.73	—	—	1.11	1.30	1.17	3.09	1.14	2.65	1.09	2.11	7.3	35.5
Hydro	1023	1.04	1.57	1.12	1.33	1.04	2.77	—	—	1.03	1.27	1.55	2.91	1.21	2.23	1.17	2.01	6.7	36.6
Rice	—	1.00	1.18	1.14	1.17	1.00	3.38	—	—	1.05	1.91	1.22	2.18	1.11	2.63	1.09	2.08	6.6	36.0
Pearl	—	1.18	1.79	1.05	1.35	1.00	2.87	—	—	1.05	1.24	1.35	2.70	—	—	1.13[4]	1.99[4]	7.8	35.3
Corneous (local)	—	1.01	1.05	1.00	1.00	1.03	1.61	—	—	1.03	1.00	1.17	1.21	1.03	1.18	1.05	1.18	7.3	36.7
Dawn selection	904	1.03	1.68	1.16	1.46	1.00	2.50	—	—	1.15	2.10	1.37	1.30	—	—	1.14[4]	1.81[4]	6.1	34.9
Dawn	340	1.01	1.59	1.08	2.13	1.00	2.32	—	—	1.14	1.56	1.15	1.24	1.07	1.82	1.08	1.78	5.7	35.3
Sunrise	472	1.07	2.38	1.33	3.36	1.13	3.68	—	—	1.37	2.84	1.93	3.48	1.40	3.76	1.37	3.25	5.9	35.8
Marum	566	1.07	1.24	1.05	1.08	1.00	3.00	—	—	1.00	1.09	1.27	1.85	1.04	2.18	1.07	1.74	6.0	36.2
White	370	1.04	1.10	1.04	1.10	1.00	1.50	—	—	1.06	1.04	1.21	1.18	1.05	1.82	1.07	1.29	6.9	36.1
Pink	432	1.03	1.14	1.00	1.04	1.00	2.48	—	—	1.01	1.23	1.16	1.14	1.06	1.43	1.04	1.41	6.3	36.6
Early Red	866	1.07	1.10	1.10	1.04	1.00	1.74	—	—	1.01	1.00	1.11	1.10	1.05	1.18	1.06	1.19	6.6	36.1
Red (No. 7)	—	1.04	2.43	1.43	2.50	1.01	3.48	—	—	1.25	1.96	1.71	3.33	1.29	3.41	1.29	2.85	7.0	36.1
Red	34	1.03	1.20	1.04	1.09	1.01	1.55	—	—	1.00	1.00	1.21	1.18	1.23	1.50	1.09	1.25	9.5	37.2
African	663-II	1.05	1.29	1.05	1.10	1.00	1.45	—	—	1.00	1.00	1.21	1.32	—	—	1.06[4]	1.23[4]	6.8	37.0
Average (18 varieties)	—	1.03	1.36	1.09	1.38	1.02	2.50	—	—	1.07	1.33	1.26	1.93	1.17	1.91	1.11	1.74	6.8	36.2
Kafir-feterita Derivatives																			
Wonder	872	1.04	2.05	1.29	1.82	1.04	2.45	—	—	1.97	2.45	1.30	2.76	1.15	2.95	1.15	2.41	6.2	36.6
Club	901	1.04	3.00	1.85	3.83	1.11	3.83	—	—	1.70	3.52	1.74	3.86	—	—	1.49[4]	3.61[4]	7.8	35.5
Premo	873	1.08	1.27	1.03	1.43	1.18	2.41	—	—	1.27	1.65	1.31	3.23	1.23	2.59	1.18	2.10	7.1	36.0
Chiltex	874	1.06	2.71	1.10	2.00	1.39	3.45	—	—	1.28	1.83	1.38	3.43	1.59	3.09	1.30	2.75	7.2	35.8
Ajax	968	1.00	1.95	1.02	1.87	1.21	3.14	—	—	1.28	2.50	1.60	3.86	1.52	2.91	1.27	2.71	6.2	36.0
Kaferita	811	1.07	2.00	1.02	1.79	1.19	3.22	—	—	1.25	1.91	1.29	3.19	1.26	2.86	1.18	2.50	8.9	35.3
Kaferita	812	1.14	2.81	1.07	2.13	1.74	3.73	—	—	2.06	2.75	1.91	3.74	2.90	3.45	1.80	3.10	10.2	35.3
Dwarf Brown kaferita	—	1.15	2.57	1.08	2.48	1.37	3.86	—	—	1.39	2.41	1.63	3.40	1.60	3.24	1.37	2.99	7.0	36.9
Average (7 varieties)	—	1.08	2.19	1.09	1.93	1.30	3.18	—	—	1.37	2.21	1.49	3.37	1.61	3.01	1.32	2.65	7.5	36.0
Feterita																			
Standard	182	1.67	3.52	1.90	4.08	1.45	5.05	1.99	4.84	1.26	3.39	1.87	5.00	2.41	4.61	1.76	4.28	8.6	35.3
Spur	623	1.08	2.62	2.01	2.73	1.26	3.41	—	—	1.38	2.56	1.16	2.71	—	—	1.38[4]	2.81[4]	8.3	34.7
Dwarf	810	1.08	1.78	1.35	2.08	1.00	1.61	—	—	1.02	1.52	1.44	3.86	1.20	2.73	1.18	2.26	8.0	36.6
Hybrid Dwarf	867	1.98	3.00	2.06	3.43	1.32	2.86	2.23	4.60	1.50	3.19	1.48	3.53	1.84	3.43	1.70	3.24	9.9	37.3
—	693	2.02	4.24	2.01	4.88	1.65	5.09	3.04	4.87	1.35	3.83	2.34	6.80	2.36	5.86	1.96	5.12	9.2	35.9
Red	693-R	1.06	2.78	1.45	3.65	1.47	3.96	—	—	1.80	3.17	1.96	4.57	1.74	3.38	1.58	3.59	7.4	35.8
—	745	2.77	4.55	2.31	5.92	2.08	5.30	2.97	3.45	1.71	3.69	2.32	4.81	1.98	4.19	2.20	4.74	8.8	34.4
—	749	1.61	3.18	1.57	3.61	1.25	4.17	2.09	3.57	1.15	3.38	1.68	4.81	1.81	3.68	1.51	3.81	7.8	35.8
White	755	2.62	4.91	1.73	4.69	2.01	4.70	2.26	4.64	1.62	4.14	2.82	6.76	2.42	6.05	2.20	5.21	8.5	35.1
Average (8 varieties)	—	1.85	3.50	1.80	4.04	1.53	4.09	—	—	1.43	3.29	1.99	5.02	1.97	4.24	1.76	4.03	8.5	35.8

[1]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
[2]Accession number of the Division of Forage Crops and Diseases.
[3]Four-year average.
[4]Five-year average.
[5]Accession number of the Division of Plant Exploration and Introduction, for Office of Seed and Plant Introduction.
[6]Includes the varieties in all groups (except miscellaneous) grown in all six years.

TABLE 1.—*Concluded.*

Variety	C. I.[1] No.	Number of stalks per plant																Average plant spacing, inches	
		1930		1931		1932		1934		1935		1936		1937		Six-year average			
		Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick	Thin
Durra																			
Early Dwarf S. P. I. 57045[5]	—	1.11	2.59	1.17	1.70	1.42	2.32	1.15	2.14	1.00	1.44	1.17	2.00	1.20	1.71	1.18	1.96	6.6	35.6
Standard White	978	1.01	1.43	1.08	1.09	1.21	1.39	1.03	1.21	1.00	1.00	1.09	1.09	1.08	1.05	1.08	1.18	7.8	35.8
White (erect)	81	1.02	2.74	1.04	1.78	1.16	2.62	1.04	1.93	1.00	1.16	1.20	1.27	1.12	1.14	1.09	1.79	7.3	37.0
Corneous	695	1.06	1.10	1.08	1.17	1.40	1.75	—	—	1.09	1.62	1.09	1.54	1.21	1.23	1.16	1.40	10.3	35.3
"Pig-nose"	696	1.03	1.05	1.05	1.00	1.11	1.05	—	—	1.00	1.00	1.03	1.00	1.05	1.00	1.05	1.02	9.5	35.3
Average (5 varieties)	—	1.05	1.78	1.08	1.35	1.26	1.83	—	—	1.02	1.24	1.12	1.38	1.13	1.23	1.11	1.47	8.3	35.8
Hegari																			
Dwarf	620	1.27	3.19	—	—	1.89	3.67	—	—	1.71	3.33	2.42	4.82	2.70	4.86	2.00[4]	3.97[4]	7.5	37.1
Dwarf	750	1.27	4.44	—	—	1.89	3.73	—	—	2.21	4.09	2.51	5.18	2.38	4.96	2.05[4]	4.48[4]	6.9	36.8
Average (2 varieties)	—	1.27	3.82	—	—	1.89	3.70	—	—	1.96	3.71	2.47	5 00	2.54	4.91	2.03[4]	4.23[4]	7.2	37.0
Kaoliang																			
Blackhull	310	1.17	3.10	1.23	4.26	1.66	5.30	1.89	2.95	1.46	3.58	1.83	4.00	1.80	4.27	1.53	4.10	6.6	42.0
White	636	1.01	2.95	1.40	2.86	1.76	4.09	—	—	2.05	2 81	1.80	3.15	1.37	2.86	1.57	3.12	9.1	35.8
White	792	1.02	1.14	1.07	1.14	1.33	3.45	—	—	1 56	2.52	1.15	1.95	1.05	1.43	1.20	1.94	7.8	36.1
White S. P. I. 46676[5]	—	1.00	1.11	1.11	1.38	1.21	2.27	1.01	1.11	1.08	1 35	1.08	1.27	1.02	1.18	1.08	1.43	8.3	36.7
Shantung	293	1.04	1.00	1.00	1.17	1.09	2.27	—	—	1 00	1.05	1.05	1.09	1.03	1.00	1.04	1.26	7.3	35.5
Manchu Brown	171	1.00	1.00	1.00	1.30	1.21	2.18	1.00	1.26	1.05	1.33	1.02	1.05	1.00	1.09	1.05	1.33	8.0	36.3
Valley	309	1.02	1.61	1.08	2.52	1.43	3.73	1.22	1.43	1.15	3.14	1.27	2.89	1.27	2.33	1.20	2.70	6.4	37.4
Early	791	1.00	1.71	1.03	2.48	1.33	3.00	1.07	2 39	1.01	2 32	1.13	2.14	1.01	1.29	1.09	2.16	7.1	36.9
Brown S. P. I. 46677[5]	—	1.03	1.62	1.03	1.61	1.27	3.57	1.00	1.37	1.10	1.65	1.14	1.75	1.04	1.09	1.10	1.88	6.1	35.2
Broom	799	1.00	1.00	1.09	1.00	1.08	1.52	1.00	1.10	1.04	1.00	1.15	1.14	1.02	1.00	1.06	1.11	7.4	36.1
Average (10 varieties)	—	1.03	1.62	1.10	1.97	1.34	3.15	—	—	1.25	2.08	1.26	2.04	1.16	1.75	1.19	2.10	7.4	36 8

Miscellaneous Grain Sorghums																			
Shallu	85	1.18	3.57	1.66	3.38	1.26	4.45	—	—	1.67	3.26	2.10	3.23	2.22	6.00	1.68	3.98	6.4	35.8
Darso	615	1.05	1.09	1.00	1.00	1.00	1.86	1.00	1.08	1.01	1.04	1.06	1.10	1.02	2.00	1.02	1.35	6.3	35.8
Schrock	616	1.13	2.38	1.09	1.41	1.00	2.18	—	—	1.01	1.18	1.70	2.86	1.40	2.27	1.22	2.05	6.8	36.6
Sagrain	—	1.15	2.62	1.26	2.58	1.05	1.83	—	—	1.01	1.81	1.74	2.65	1.68	3.00	1.32	2.42	6.1	36.4
Grohoma	920	—	—	1.10	2.43	1.09	2.33	—	—	1.08	2.36	1.64	3.57	1.31	3.14	1.23[4]	2.77[4]	7.0	35.8
Dwarf Freed	971	1.45	3.57	1.61	3.39	1.19	2.68	1.60	4.26	1.05	2.32	1.35	3.20	1.29	3.45	1.32	3.10	6.7	36.6
Freed	350	1.39	3.25	2.00	4.00	1.41	3.27	2.53	4.13	1.57	2.64	1.52	3.57	1.51	3.55	1.57	3.38	7.5	46.5
Kansas Orange x milo	894	1.08	1.18	1.15	2.04	1.17	2.00	1.00	1.41	1.02	1.42	1.03	1.13	1.10	1.27	1.11	1.51	7.5	34.7
Sorgo																			
Early Amber	—	1.29	4.25	1.48	4.04	1.44	3.91	2.18	5.14	1.47	2.95	2.48	4.86	2.26	4.55	1.74	4.09	6.8	36.9
Black Amber F. C. 7038[2]	—	1.05	3.24	1.23	4.05	1.02	2.83	1.26	4.36	1.04	2.19	2.04	4.17	1.50	4.10	1.31	3.43	7.2	36.1
Red Amber F. C. 9092[2]	—	1.17	2.81	1.20	3.35	1.11	3.33	—	—	1.07	3.24	1.59	4.35	—	—	1.23[4]	3.42[4]	6.4	36.5
Leoti	—	1.11	2.57	1.36	2.13	1.06	2.22	—	—	1.01	1.62	1.27	2.23	1.32	2.27	1.19	2.17	7.7	36.1
Orange (Cron)	—	1.07	1.90	1.19	2.17	1.03	2.04	1.11	2.17	1.06	1.73	1.15	1.79	1.12	2.32	1.10	1.99	6.6	35.3
Kansas Orange	—	1.06	2.90	1.26	2.91	—	—	—	—	1.10	2.29	1.44	3.19	1.33	2.91	1.24[4]	2.84[4]	6.1	36.6
Colman	—	1.17	2.91	1.39	4.42	1.03	3.77	—	—	1.12	3.33	1.76	4.41	1.26	4.18	1.29	3.84	6.5	35.8
Sourless F. C. 9111[2]	—	1.09	3.24	1.38	4.70	—	—	—	—	1.18	3.52	1.74	4.41	1.64	4.68	1.41[4]	4.11[4]	5.9	36.3
African Millet	—	1.06	2.24	1.24	4.32	1.08	3.50	—	—	1.12	3.10	1.39	3.43	1.28	3.53	1.20	3.35	6.2	37.8
Early sumac	—	1.07	2.62	1.36	3.09	1.09	2.27	—	—	1.24	2.62	1.16	2.35	1.34	2.05	1.21	2.50	6.0	36.9
Sumac F. C. 1712[2]	—	1.09	3.19	1.50	4.04	1.17	3.55	—	—	1.08	2.00	2.00	4.30	1.69	4.00	1.42	3.51	5.9	38.0
Sumac S. P. I. 63715[5]	—	1.09	3.10	1.27	4.35	1.16	4.05	—	—	1.25	2.95	1.85	4.24	1.80	4.62	1.40	3.80	6.2	37.2
Collier	—	1.09	2.57	1.12	2.78	1.03	3.35	—	—	1.10	2.00	1.76	2.67	—	—	1.22[4]	2.67[4]	9.2	36.6
Atlas	899	1.24	3.25	1.20	3.35	—	—	—	—	1.72	2.92	2.00	3.68	1.44	3.45	1.52[4]	3.33[4]	6.7	35.6
Average (9 varieties)	—	1.11	2.89	1.34	3.62	1.12	3.13	—	—	1.15	2.50	1.68	3.53	1.51	3.51	1.32	3.20	6.6	36.7
Grand average (79 varieties)[6]	—	1.16	2.01	1.26	2.38	1.25	2.95	—	—	1.24	2.10	1.39	2.45	1.38	2.46	1.28	2.39	7.4	36.0

[1]Accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.
[2]Accession number of the Division of Forage Crops and Diseases.
[3]Four-year average.
[4]Five-year average.
[5]Accession number of the Division of Plant Exploration and Introduction, for Office of Seed and Plant Introduction.
[6]Includes the varieties in all groups (except miscellaneous) grown in all six years.

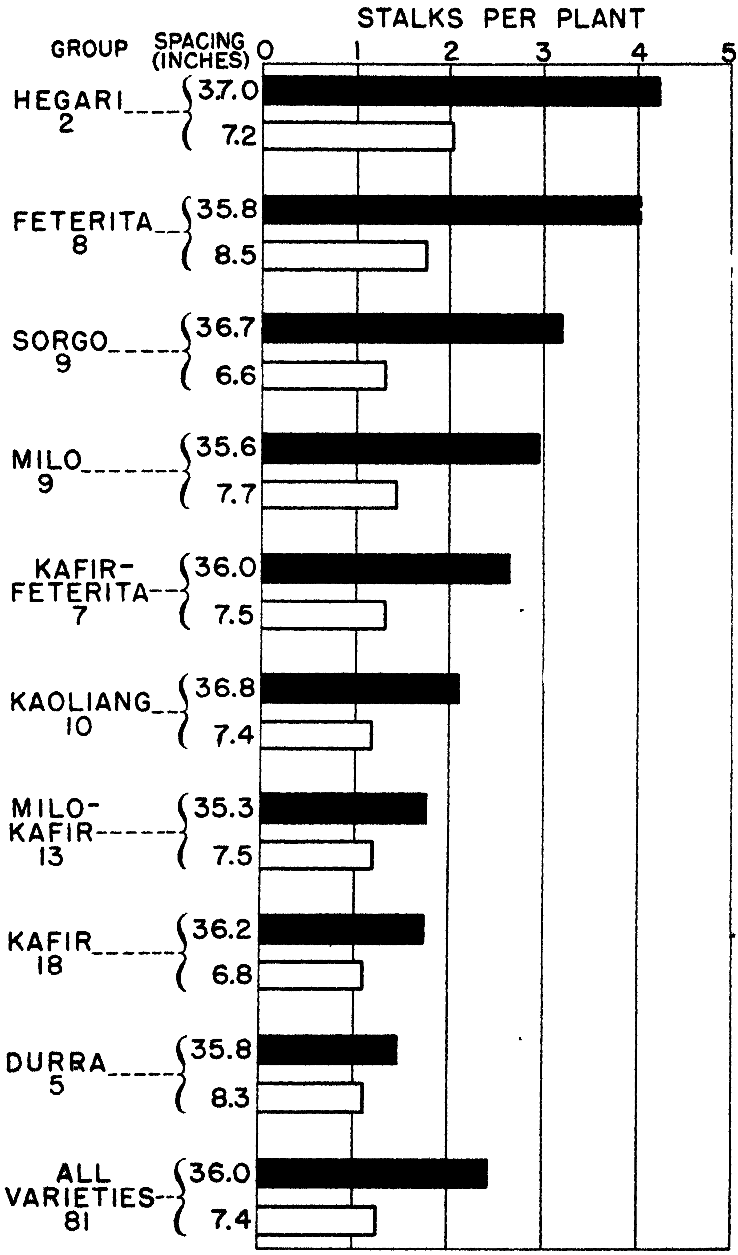

FIG. 1.—Average number of stalks per plant in thick and thin spacing in nine sorghum groups and the average for 81 varieties.

is due to the thicker average spacing of sorgo (6.6 inches) as compared with those of feterita (8.5 inches) and milo (7.7 inches). Sorgos ordinarily are spaced rather thickly in order to secure maximum forage yields, and their generally high tillering capacity as shown in the thin spacing often has not been evident in ordinary field experiments.

Varieties selected from crosses between kafir and feterita tended to be intermediate between the parental types in tillering ability. Varieties selected from kafir-milo hybrids, on the other hand, tended to approach the kafir parent in tillering ability. In this group only the Wheatland backcross and Bishop tended to approach the Dwarf Yellow milo parent in the number of tillers produced.

The average number per plant among the 79 sorghum varieties grown all six years was 1 28 stalks (0.28 tillers) in the thick spacing and 2 39 stalks (1.39 tillers) in the thin spacing. The average ratio between the thick and thin spacings was 1.87 for stalks per plant and 4 96 for tillers. For the various groups the ratio of stalks per plant in the two spacings ranged from 1.32 in durra to 2.42 in sorgo.

Considerable differences are observed in tillering among varieties within a group, as might be expected. The Dwarf Yellow variety (C. I. 332) showed the highest average tillering capacity among the milos and Day was the lowest. In the kafir-milo group, Wheatland backcross was the highest and Smith milo×kafir was the lowest in tillering capacity Wheatland showed appreciably higher tillering capacity than Beaver Among the kafirs, Sunrise was high and Corneous was low Another kafir showing high tillering capacity was Red kafir No. 7, which was selected from a Sunrise hybrid. Of the kafir-feterita derivatives, Club was high and Premo low. The feterita parentage of Club is merely assumed from plant characters, as the exact origin of this variety is not known.

Among the feteritas, Dwarf and Spur were distinctly low in the number of tillers per plant. All of the five durras tillered rather poorly and the "Pig-nose" variety developed almost no tillers, even in the thin spacing The kaoliangs showed a wide range in tillering. The Blackhull variety, highest in the group, had an excessive average spacing of 42 inches. It also has certain characteristics which indicate that it might have become crossed with a feterita at some time before seed was sent to Woodward in 1914. All of the sorgos tillered freely except Leoti and the Cron strain of Orange.

Among the miscellaneous varieties, darso had few tillers, shallu had many, and Grohoma was slightly above the average for all varieties.

The tillering of the 105 varieties listed in Table 1 is shown graphically in Fig. 2, with the varieties arrayed in the order of the average number of stalks per plant in the thin (36-inch) spacing. "Pig-nose" durra shows the least tillering tendency and White feterita (C. I. 755) the greatest. In the lower two-fifths of the varieties in which the thin spacing produced not more than 2.00 stalks per plant and the thick spacing, with two exceptions, 1.20 stalks or less, will be found all of the durras, all but five of the kafirs, and most of the kaoliang varieties. Those that tiller freely, found in the upper fourth of the

varieties, produced 3 or more stalks per plant in the thin spacing and, with six exceptions, 1.40 or more stalks per plant in the thick spacing.

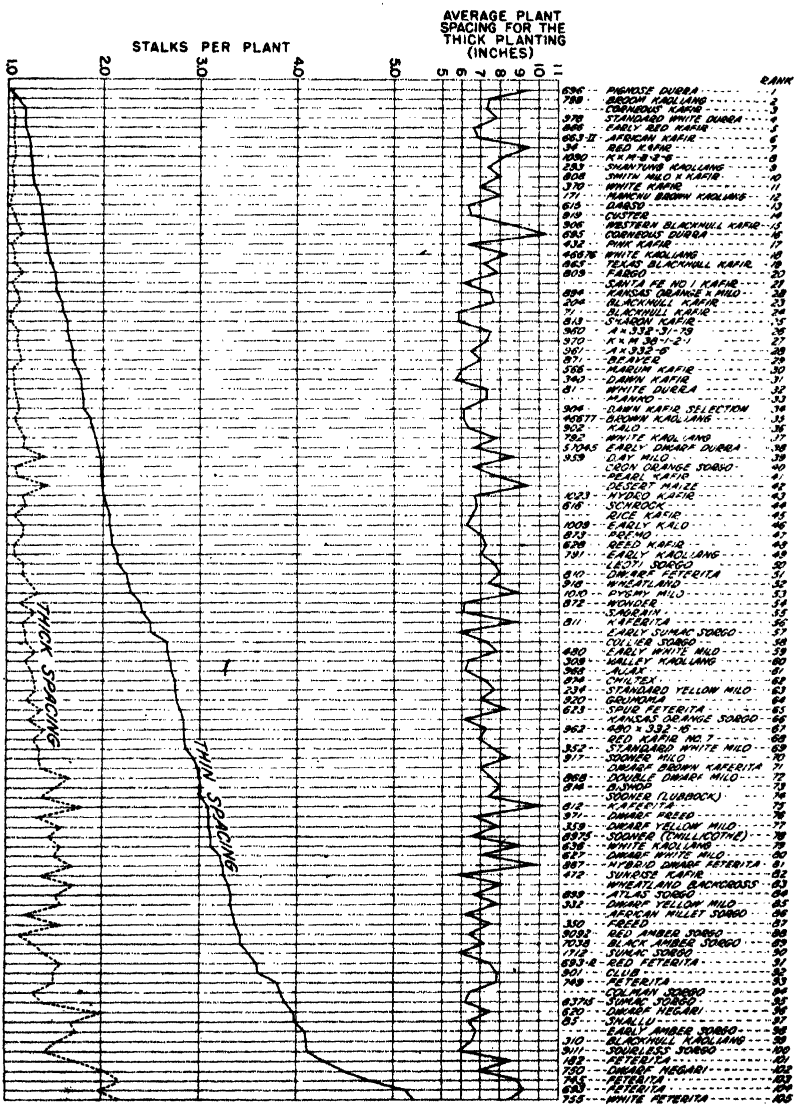

FIG. 2.—Average number of stalks per plant in thick and thin spacing of 105 sorghum varieties.

This high class contains both strains of hegari, all but 2 feteritas, 9 of the 14 sorgos, and 5 of the 13 milos. In the intermediate class are found Standard Yellow milo, Standard White milo, Early White

milo, Double Dwarf Yellow milo, and 5 of the 6 milo varieties that originated from crosses between Early White milo and Dwarf or Double Dwarf Yellow milo, *viz.*, Pygmy (C. I. 962), and the two strains of Sooner. Day milo produced slightly less than 2 stalks per plant.

Varieties of about average tillering ability include Wheatland, Sagrain, and kaferita (C. I. 811).

The number of stalks per plant, in general, follows the same varietal trends for the two spacings (Fig. 2), although varietal differences are smaller in the thick spacing. Exceptions to this trend are due largely to variations in the thick spacing above or below the average of 7.4 inches, as shown in Fig. 2. In the thick spacing a range of 4 inches in spacing, as would be expected, is much more important in tiller development than the same range in the thin spacing.

Hegari appears to differ from feterita in its tendency for tillering in thick spacing since it produced 2.03 stalks per plant in the thick spacing in which its average spacing was only 7.2 inches; whereas the feterita group produced only 1.76 stalks per plant with an average spacing of 8.5 inches. Both varieties of hegari are noticeably high in tillering in the thick spacing, as shown in Fig. 2, despite the fact that the actual spacing was about average for all the sorghums.

"Pig-nose" durra produced 1.05 stalks per plant in the thick spacing and only 1.02 stalks per plant in the thin spacing; tillering in this variety apparently was not affected by variations in spacing. Other varieties of low tillering capacity, as measured by the number of stalks per plant in the thin spacing, were affected only slightly by variations from the mean spacing of all varieties in the thick spacing. Varieties with a higher tillering capacity show a distinct response to variations from the 7.4-inch spacing.

DISCUSSION

The actual merits of tillering in sorghum production are difficult to evaluate, although it has been shown (2) that under favorable conditions tillers produce more than enough grain and stover to offset the decreased growth of the main stalk. The durras appear to be definitely limited in grain yield, even under favorable conditions, and the limited tillering may be largely responsible. Darso and Blackhull kafir show little tendency to tiller, but these varieties are among the most productive of grain in average seasons in the central and eastern portions of Kansas, Oklahoma, and Texas. It would appear that these varieties, with the stands ordinarily obtained, have sufficient stalks to develop as much grain as other factors affecting yields usually permit. Variations in head size in response to environmental differences help maintain the yields of these varieties. Their resistance to chinch-bug injury also is an important factor tending to favor them over other varieties with higher potential yields in the sections above mentioned.

Reed kafir, which tillered rather poorly in earlier plat experiments (7) but yielded best when the plants were about 6 inches apart, has ranked at or near the top in grain yield among the sorghums tested

at several western field stations in Oklahoma, Texas, and New Mexico. The exact reasons for this are not now ascertainable, but the ability of the Reed variety to tiller well in comparison with other kafirs when stands are thin may furnish a partial explanation. Irregularities in stand thus would be partly compensated for by the development of tillers in the Reed variety.

Sunrise and Dawn kafir offer an interesting comparison. These two varieties were selected from a single headrow grown from an early-maturing plant of kafir. Sunrise usually is about 1½ feet taller than Dawn and tillers much more freely, but otherwise the varieties are nearly identical. Sunrise, in general, produces about as much grain and considerably more stover than Dawn. As a rule, taller stalks and additional stover are associated with a corresponding reduction in grain yield as compared with other varieties having similar plant characteristics and the same length of growing period. It seems reasonable to assume that the additional tillers produced by Sunrise account for the grain yields nearly equal to those of Dawn, despite the higher production of stover in Sunrise. The similarity of Sunrise kafir and several sorgos in tillering behavior furnishes additional evidence that the strain of kafir from which it was selected may have been a segregate from a natural hybrid between a kafir and a sorgo.

Club, which was selected from Dawn kafir, but which probably was derived originally from a natural hybrid between kafir and feterita, has a tillering capacity very similar to that of feterita. The superior grain yields of Club in the Great Plains region, as compared with those of kafirs, possibly may be the result of better tillering ability.

Hegari has long been observed to tiller rather heavily despite unfavorable environmental conditions. This tendency to produce tillers regardless of spacing or season is shown in Table 1. Tillers on hegari plants usually develop during early stages. Hegari produces high yields of grain in a suitable temperature environment when ample moisture is present, but under dry conditions the excessive tillers apparently exhaust the available moisture supply and little or no grain is produced.

Dwarf Yellow milo usually tillers heavily, but the tillers often develop later than the main stalk and then largely in response to favorable environment. This tillering response largely accounts for the extreme adaptability of milo to varying spacing and moisture conditions. Milo under irrigation has produced the highest grain yields of any grain sorghum recorded in this country. Grain yields of 120 to 180 bushels per acre cannot be attained without considerable tillering when the plants are grown in rows 3 feet or more apart. Milo also is the outstanding sorghum for grain in the dry southwestern portion of the Great Plains area. There tillering in milo is limited when conditions are unfavorable and the plants usually produce a small crop of grain in severe seasons. The crop shows a strong response, however, to any additional moisture that is made available from summer fallowing or other practices supplying extra moisture. Of more importance, perhaps, than this moisture response is the ability of milo to tiller freely in order to compensate for additional space per plant

(4, 5, 10). Irregular stands of milo are not particularly detrimental to yield. Recent experiments under average Great Plains conditions have shown that milo yields vary only slightly when plant spacing within the row ranges from 6 inches to 6 feet. Such uniformity of yields can be attained only in a variety in which tiller development is sensitive to environment.

It is significant that varieties such as milo and hegari having a capacity for high grain yields of 75 bushels per acre or more under very favorable conditions also have a relatively high tillering ability. The heavy tillering of feterita and medium tillering of certain varieties of kaoliang, although probably favorable to high grain yields, cannot overcome the handicap of early maturity, slender, sparsely-leaved stalks, and frequent small heads, as compared with the higher yielding varieties of milo and hegari. Varieties having high potential grain yields such as Ajax and Grohoma are only slightly above average in tillering ability, but heavy heads and stalks and a long growing period make these varieties superior to feterita under favorable growing conditions.

Thick- and thin-spacing experiments reveal certain plant responses in addition to tillering. White durra (C. I. 81) was distributed because of its erect panicles, whereas the original White durra variety from which this strain was selected has recurved or "gooseneck" heads. The selected strain in ordinary field plat experiments and in the thick spacing in these experiments has always produced erect heads In the thin spacing, however, during several seasons the heads of this variety were so thick and heavy when they emerged from the sheath that they were all recurved.

Another striking response in the spacing experiments has been the variation in the height of the plants. In ordinary seasons plant competition (probably for light) caused the stalks in the thick spacing to be appreciably taller than in the thin spacing. In dry seasons, however, the height relationship was reversed because the competition for moisture in the thick spacing was so severe that it caused stunting.

Thin spacing, as might be expected, encouraged the development of nodal branches on the sorghum stalks.

The chief value of these tillering data are in serving as a guide for the proper spacing of varieties. Results previously cited (4, 5, 7, 10) suggest that varieties which tiller poorly should be planted relatively thick for maximum grain yields, usually about 6 inches apart, except under very dry conditions. Feterita plants apparently should be spaced about 12 inches apart. Milos, depending upon the tillering ability of the varieties, adapt themselves to a wide range of spacing. Recent experiments have shown that Beaver requires thicker spacing than the related variety, Wheatland, which produces more tillers. All varieties, however, produce the highest yields of forage when planted thick.

SUMMARY

The number of stalks per plant in 105 varieties of sorghum grown at Woodward, Okla., from 1930 to 1937 was determined in rows in

which the plants were spaced at two distances, *viz.*, about 7 inches and 36 inches apart.

In stalks produced per plant in the 36-inch spacing, the various sorghum groups ranked from the greatest to the least number as follows: Hegari, feterita, sorgo, milo, kaoliang, kafir, and durra. The six-year average number of stalks per plant in 79 varieties was 1.28 in the 7-inch spacing and 2.39 in the 36-inch spacing. Some varieties produced no tillers in certain seasons, but one variety produced an average of 6.8 stalks per plant in the 36-inch spacing in 1936.

The rank of the varieties in number of stalks per plant was very similar in the two spacings, except when spacing was not uniform, although varietal differences were smaller in the 7-inch spacing than in the 36-inch spacing. Small variations from the average spacing had little effect on the number of stalks per plant in the kafirs and other varieties that produced few tillers but such variations were important in many varieties that tiller freely.

Hegari produced a considerable number of tillers in all seasons and in both spacings. Dwarf Yellow and certain other varieties of milo usually tillered freely, but tillering fluctuated more with environment than in hegari.

Differences in tillering appear to account for many of the yield relationships and adaptations that have been observed in sorghum varieties. The proper plant spacing for a variety depends largely upon its tillering ability. Varieties that tiller poorly should be planted relatively thick.

LITERATURE CITED

1. BALL, C. R., and ROTHGEB, B. E. Grain sorghum experiments in the Panhandle of Texas. U. S. D. A. Bul. 698. 1918.
2. BARTEL, A. T., MARTIN, J. H., and HAWKINS, R. S. Effect of tillers on the development of grain sorghums. Jour. Amer. Soc. Agron., 27:707–714. 1935.
3. HASTINGS, S. H. The importance of thick seeding in the production of milo in the San Antonio region. U. S. D. A. Bul. 188. 1915.
4. KARPER, R. E. The contrast in response of kafir and milo to variations in spacing. Jour. Amer. Soc. Agron., 21:344–354. 1929.
5. ———, QUINBY, J. R., JONES, D. L., and DICKSON, R. E. Grain sorghum date-of-planting and spacing experiments. Tex. Agr. Exp. Sta. Bul. 424. 1931.
6. ———, ———, ———, ———. Grain sorghum varieties in Texas. Tex. Agr. Exp. Sta. Bul. 459. 1932.
7. MARTIN, J. H., SIEGLINGER, J. B., SWANSON, A. F., BURNHAM, D. R., CLEMMER, H. J., COLES, E. H., KEATING, F. E., and OSBORN, W. M. Spacing and date-of-seeding experiments with grain sorghums. U. S. D. A. Tech. Bul. 131. 1929.
8. QUINBY, J. R., STEPHENS, J. C., KARPER, R. E., and JONES, D. L. Forage sorghums in Texas. Tex. Agr. Exp. Sta. Bul. 496. 1934.
9. SIEGLINGER, J. B. Grain sorghum experiments at the Woodward Field Station in Oklahoma. U. S. D. A. Bul. 1175. 1923.
10. ———. The spacing of grain sorghums. Jour. Amer. Soc. Agron., 18:525. 1926.

EFFECT OF ARTIFICIAL DRYING UPON THE GERMINATION OF SEED CORN[1]

T. A. KIESSELBACH[2]

THE artificial drying of ear corn with heated air under forced draft is coming into rather common usage by extensive growers of hybrid seed. Under good management, this practice may remove the hazards of freezing injury, and it facilitates early harvest, storage, and processing. There are no indications that hybrid seed is in more need of artificial drying than is seed from open-pollinated varieties, but its greater value has made growers more cautious. For recent evidence of widepsread, serious freezing injury to seed corn one need but recall the year 1935 when the crop in most of the corn belt was subjected to late maturity and severe early frost. As shown in an earlier paper,[3] there is a very definite inverse relationship between the moisture content of the seed and the degree and duration of freezing temperature that it will withstand without loss of viability.

Because of the comparative newness of the practice and the inexperience of operators in commercial production, seed injury sometimes results during the drying process because of faulty manipulation. Questions frequently arise regarding suitable temperatures, length of drying, moisture relations, and reaction of different hybrids. It is the chief object of this paper to report the results of a number of tests made at the Nebraska Agricultural Experiment Station in 1937 and 1938 which bear on these problems.

DRYING EQUIPMENT

The procedure was fairly similar to that reported by Harrison and Wright[4] of the Wisconsin Experiment Station. A series of four 4 x 6 x 9 feet drying bins, installed in the Agronomy Laboratory Building, have been used with satisfaction during the past six years. With some modifications, these are patterned after those described by Wright and Duffee[5] and operate according to the same principles. The bins have a temperature range of 100° to 220° F and may be kept constant within 3° variation by thermostatic control.[6]

The air is heated by blowing over a high-pressure steam radiator by means of a fan driven by a variable speed 3-horse electric motor which delivers 2,840 cubic

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[2]Agronomist.

[3]KIESSELBACH, T. A., and RATCLIFF, J. A. Freezing injury of seed corn. Nebr. Agr. Exp. Sta. Res. Bul. 16. 1920.

[4]HARRISON, C. M., and WRIGHT, A. H. Seed corn drying experiments. Jour. Amer. Soc. Agron., 21:994–1000. 1929.

[5]WRIGHT, A. H., and DUFFEE, F. W. The bin method of drying seed corn. Mimeographed circular from the Departments of Agronomy and Agricultural Engineering, Wisconsin College of Agriculture. 1929.

[6]Although only the lower temperature range is needed for drying seed, the higher heat capacity was provided for use in connection with yield tests to reduce representative samples of grain and forage to a comparable and essentially moisture-free condition.

feet of air per minute at 900 r.p.m. and 5,700 cubic feet at 1800 r.p.m. The combined volume of the four bins is 864 cubic feet. For economy, the heated air is partially used over again, some fresh air being continually introduced. At 12-hour intervals, the direction of the air is reversed to enter the bins alternately from above and below.

For the various tests herein described the initial bin temperature was brought to the desired degree and continued constant. The actual temperatures and length of drying intervals are given in the tables.

TESTING FOR GERMINATION

Soon after the drying was completed, germination tests were run at 85° F by the rag-doll method. Each lot of ears was tested in duplicate, using 200 kernels picked at random in equal numbers from each ear. The kernels were classed as germinated if both plumule and root grew. Comparative germination vigor was noted.

RESULTS

EFFECTS OF INITIAL MOISTURE, TEMPERATURE, AND DURATION OF DRYING

Moisture variations of corn tested.—In 1937 mature ear corn of the Krug variety was harvested from the field on September 16 and immediately divided on the basis of appearance and feel into three groups representing low, medium, and high moisture content. The mean moisture contents in the grain of these respective groups were 19, 27, and 30%. A similar harvest and grouping of ears was made on September 22 when the respective moistures were 13, 19, and 23%. The drying tests were started on the day of harvest as soon as the ears were classified. No killing frosts had occurred at the time of gathering the corn from the field.

In the fall of 1938, two similar harvests were made on September 14 and September 20, for the purpose of studying the effect of higher moisture contents than those of 1937. The ears picked on each date were divided into two groups averaging 50 and 57% moisture on September 14 and 49 and 56% moisture on September 20.

Temperature and duration of the drying period.—Recommended seed-drying temperatures have come to be fairly well standardized at between 105° and 110° F. In these experiments, the ears picked at the first harvest each year were dried at 112° F, while those of the second harvest were dried at 107° F. Such procedure was necessary because only one temperature could be maintained at a time by the equipment available.

The ears of each moisture group were randomly divided into several lots of 20 ears each for drying at varying intervals. There were 11 such lots of the low moisture group in 1937 and 6 lots of all other groups each year.

One lot of each group dried naturally at room temperature, approximately 70° F. All other lots in each test were placed in the drying bin simultaneously but were withdrawn successively at 24-hour intervals. Moisture determinations of representative grain samples were made for each lot in 1937 at the close of their drying periods.

Results.—The data obtained in 1937 and 1938 are reported in Tables 1 and 2, respectively. At 112° F there were no significant effects on the percentage or vigor of germination for seed averaging 19, 27, and 30% moisture. Even after 5 days of drying, when the seed had reached a moisture content of about 5%, these moisture groups gave the respective germinations of 97.5, 99.5, and 99.5%. Subjected to slow natural drying, their germinations were 98.5, 99.0, and 99.5%. When the grain contained as high as 50 and 57% moisture at time of placing in the drying bin, the germination rather gradually fell off in five days to 90.5 and 83%, respectively. The vigor of sprouts was also greatly reduced at these high moisture contents.

At 107° F there also were no significant effects on either the percentage or vigor of germination for the three lowest moisture groups containing 13, 19, and 23% moisture, respectively. After five days of drying when the moisture had been reduced to about 6.5%, the respective germinations were 98.1, 97.9, and 97.0%. Corresponding naturally dried samples germinated 98, 97, and 98%. When the grain contained 49 and 55% moisture as husked, the respective germinations were 97.5 and 82%. At 49% initial moisture, the seed satisfactorily withstood drying at 107° F and gave strong, vigorous sprouts at all drying intervals. At the higher initial moisture, 55%, however, the vigor of the sprouts as well as the percentage germination were materially reduced.

Ear corn subjected to the non-harmful temperature of 107° F for as long as 35 days reached a moisture content of 4.3% and had not fluctuated more than 0.2% during the preceding 28 days. At the end of this period the seed germinated 98% or the same as the naturally dried seed.

DIFFERENTIAL RESPONSE OF HYBRIDS

In order to get some indication as to whether there are important heritable differences in the response of corn to artificial drying, 26 comparably grown single crosses were dried for a period of 5 days at 112° F. This relatively high temperature was used since it might be expected to be more selective of heat-susceptible hybrids than a lower temperature.

Five mature ears of each hybrid were picked on September 14. Their mean moisture contents before drying and their percentages of germination after drying are reported in Table 3. There was considerable moisture variation because of difference in time of maturity. The extreme range of germination was 96 to 100%, while only one hybrid fell under 97.5%. These data indicate no important differential response for the different hybrids. Under conditions of commercial production the seed would not be subjected to so long a drying period and there would be even less likelihood of injury than in these experiments. There is of course a possibility of differential response at temperatures higher than that here employed, but higher temperatures are regarded as hazardous and are not recommended.

Were such a collection of hybrids harvested under conditions of higher mean moisture content, ranging perhaps between 35 and 60%, it is possible that variable injury from artificial drying would be

TABLE 1.—*Effects of artificially drying ear corn differing in moisture content at 112° and 107° F for various intervals under forced draft upon the drying rate and viability of the seed, 1937.*

Classification of ear corn as to moisture content	Percentage moisture in grain						Percentage germination* of seed after						
	When harvested	After artificial drying					Natural drying	Artificial drying					
		1 day	2 days	3 days	4 days	5 days		1 day	2 days	3 days	4 days	5 days	Av.
Drying Temperature 112° F (Test Begun Sept. 16)													
Low	19.0	9.3	6.0	5.0	5.1	5.0	99	100	100	99	99	98	99
Medium	27.0	12.5	9.4	6.0	5.0	5.0	99	100	100	100	100	100	100
High	30.1	15.2	12.0	6.5	5.0	5.4	100	99	100	98	99	100	99
Average	25.4	12.3	9.1	5.8	5.0	5.1	99	100	100	99	99	99	99
Drying Temperature 107° F (Test Begun Sept. 22)													
Low†	13.0	8.2	6.2	6.6	6.6	5.8	98	98	98	99	99	98	98
Medium	19.4	11.8	9.2	6.2	6.8	6.6	97	97	97	98	100	98	98
High	23.4	14.8	10.0	7.0	6.4	6.5	98	94	97	100	98	97	97
Average	18.6	11.6	8.5	6.6	6.6	6.3	98	96	97	99	99	98	98

*No differences were noted in the vigor of germination.

†Corresponding samples with initial low moisture content were continued at the temperature of 107° F for the periods of 6, 7, 8, 9, 10, and 35 days. At these prolonged intervals of drying, the respective moisture contents of the grain were 5.4, 5.5, 5.0, 5.2, 5.0, and 4.3%, while corresponding germinations were 98.0, 98.0, 97.5, 96.5, 98.5, and 98.0%.

TABLE 2.—*Effects of artificially drying ear corn of high moisture content at 112° and 107° F for various intervals under forced draft upon the viability of the seed, 1938.*

Classification of ear corn as to moisture content	Moisture in grain when harvested, %	Germination after natural drying, %	Percentage germination of seed after artificial drying					Percentage vigor* of germination after artificial drying					
			1 day	2 days	3 days	4 days	5 days	0 day	1 day	2 days	3 days	4 days	5 days
Drying Temperature 112° F (Test Begun Sept. 14)													
Very high	49.9	97.0	96.5	92.0	93.5	90.0	90.5	95	92	80	85	78	78
Extra high	57.1	97.5	93.5	89.0	89.5	84.0	83.0	93	80	75	73	72	73
Average	—	97.3	95.0	90.5	91.5	87.0	86.8	94	86	78	79	75	75
Drying Temperature 107° F (Test Begun Sept. 20)													
Very high	49.2	98.5	98.0	99.0	98.5	97.0	97.5	95	95	95	95	93	95
Extra high	55.4	96.0	92.5	89.5	85.5	85.0	82.0	95	90	85	75	77	75
Average	—	97.3	95.3	94.3	92.0	91.0	89.8	95	93	90	85	85	85

*The vigor of germination is based on an arbitrary scale ranging between 70 and 95%, in which 70 signifies decided inferiority and only about one-half as much sprout growth as 95.

apparent. This would seem due, however, to difference in moisture content rather than heritable susceptibility.

TABLE 3.—*Effect of artificially drying mature ear corn of 26 single-cross hybrids for five days under forced draft at 112° F upon the viability of the seed, 1938.**

Hybrid	Moisture content of ear corn, %	Germination, %	Hybrid	Moisture content of ear corn, %	Germination, %
K×1628×K 1605	34.3	99.0	WR 1999×K 1558	26.0	99.5
I 420×A	24.1	97.5	I 234×K 1620	19.3	98.0
I 205×L 289	22.3	99.5	N6×K 1620	33.3	99.0
GR 87×L	37.8	97.5	K 1619×WR 1999	31.3	99.5
Os 426×I 197	18.8	99.0	RR 1756×2144	16.1	100.0
R4×GR 100	19.7	99.5	N6×L 317	36.6	98.5
K 1637×HG 7487	30.2	100.0	I 205×K 1620	29.4	100.0
Os 420×K 1616	29.8	96.0	WR 1916×BuR 1768	21.1	100.0
I 197×GR 87	29.2	99.5	Os 420×Os 426	27.2	100.0
K 1650×2083	31.6	99.0	R4×L 317	27.3	99.0
R4×GR 87	28.5	99.0	I 234×L 289	16.7	100.0
Hy×CC 1862	26.3	99.5	L 289×N6	24.1	99.5
K 1562×WR 1916	20.8	99.0	K 1515×BuR 1829	20.0	99.0

*No differences were noted in the vigor of germination, all being satisfactory

MOISTURE ABSORPTION BY SEED AFTER EXCESSIVE DRYING

For the purpose of studying the rapidity of atmospheric moisture absorption after excessive drying, bulk samples of both ear and shelled corn containing 6% moisture were exposed in burlap bags for 12 days in the seed room at about 70° F and thereafter for 12 days in an open, unheated shelter. During the first 12-day interval, the moisture content of the ear and shelled corn rose respectively to 7.3 and 7.4%. At the end of the second 12-day period the respective moisture contents had risen to 9.0 and 10.7%, the latter being a close approach to an air-dry equilibrium under the conditions.

DISCUSSION

The objectives of artificially drying seed corn are attained as soon as the seed is reduced to a moisture content safe from storage and freezing injury. Drying beyond such point would be needless expense. It has been ascertained that seed containing not to exceed 14% moisture will withstand any degree of cold and may be stored without loss of quality or viability. For commercial seed production, drying to a mean moisture content of 12 to 13% is recommended. Drying of the bulk seed slightly below the upper limit of tolerance will tend to insure against some of the kernels being insufficiently dried.

To illustrate, the grain of a bulk sample of Krug ear corn averaged 25% moisture when husked. When the ears were sorted into three equal groups according to apparent moisture content, the three lots contained 19, 27, and 30% moisture, respectively. After artificial drying at 112° F for 24 hours the mean moisture content had been reduced to 12.3%, but that of the three separate lots was 9.3, 12.5,

and 15.2%. In another but similar case, the bulk ears contained 18% moisture, whereas separation according to apparent moisture gave three equal groups with 13, 19, and 23% moisture. At the end of 24 hours drying at 107° F, the mean moisture had reduced to 11.6%, while the three respective lots contained 8.2, 11.8, and 14.8% moisture. If ears of varying moisture content were mixed together in large quantity as in bulk commercial drying, there would doubtless be a greater tendency toward equalization in the drying rate of the component ears.

In commercial practice, the moisture content of representative grain should be determined at intervals during the drying process by a Duvel oil tester or other satisfactory rapid means, and the heating should be discontinued when the desired moisture content is attained. For corn containing 20% moisture, about one day of drying should suffice, while two days should be ample when the moisture content is 30%. Three days may be needed when there is 50% moisture The ears should be husked clean as the presence of many husks interferes with air circulation and retards drying. Underdrying may cause inconvenience through loss in weight during storage after the seed has been weighed into bushel bags Likewise weighed bags of seed corn that has been dried excessively will gradually absorb atmospheric moisture and gain in weight until an equilibrium is reached

In the Nebraska Agricultural Experiment Station seed-corn-drying tests, the percentage and vigor of seed germination were uninjured by artificial drying at a temperature range of 107 to 112° F when the initial moisture content of the grain did not exceed 38%. This was true even though the duration of artificial drying and the degree of desiccation materially exceeded that needed and recommended in commercial practice. However, when the moisture reached 50%, the germination was materially reduced by prolonged drying at 112° F, and with 55% or more moisture it was seriously reduced. On the other hand, at a somewhat lower temperature, 107° F, seed with 49% moisture was unaffected, while seed with 55% moisture was seriously injured.

Although immature corn with excessively high moisture content has not been extensively studied, there appears to be an inverse relation between moisture content and high-temperature tolerance. This corresponds with the previously established principle applying to the freezing injury of seed corn, in which there is an inverse relation between moisture content and low temperature tolerance.

Fully matured seed corn of reasonably low moisture content may be artificially dried at 107° to 112° F without unfavorably affecting the appearance of the seed as to color, lustre, and wrinkling of pericarp.

A field yield test of all the seed lots dried artificially in 1937 failed because of the severe drouth. Observations of field stand and seedling growth, however, disclosed no differences in relation to moisture content of the seed or to duration and degree of high temperature. The seed used in these field plantings did not exceed 30% moisture when placed in the drier and the temperature did not exceed 112° F.

All commercial and experimental lots of hybrid seed produced at the Nebraska Experiment Station have been artificially dried at 105°

to 110° F during the last five years. No ill effects from such treatment have been observed when the seed was planted in the field.

In general, these results agree with those of Harrison and Wright who found at the Wisconsin Agricultural Experiment Station that seed corn was uninjured as to germination, seedling growth, and field performance by drying in the ear to as low as 4% moisture content under forced draft at the non-harmful temperatures of 104° to 113° F. These Nebraska data would merely tend to lower the upper temperature limit in the case of corn with unusually high moisture content.

SUMMARY

The timely artificial drying of seed corn with heated air under forced draft may remove the hazard of freezing injury and facilitate early harvest, storage, and processing. If suitable procedure is followed, no injury results to viability or field performance of the seed.

In connection with such artificial drying, a reduction in the moisture content of the seed to 12 to 13% at a temperature range of 105° to 110° F is recommended except that the temperature be held as low as 105° F when the initial moisture content approaches 50%.

Prolonged drying at safe temperatures to a moisture content as low as 5% is not harmful to the seed. Such thorough desiccation is impractical, however, as it involves needless expense and time and causes inconvenience when bagged for storage in weighed quantities by gradual increase in weight through absorption of atmospheric moisture. Likewise, insufficient drying subjects the seed to later loss of weight and possible deterioration during storage. The permissible range of moisture content for safe processing and storage approximates 5 to 14%.

The length of drying interval needed to reduce ear corn to a safe moisture content varies with the initial moisture content of the grain and the drying temperature. Such duration may approximate 1, 2, or 3 days for corn containing 20, 30, and 50% moisture, respectively, provided the air is sufficiently changed.

There appears to be an inverse relation between drying temperature and minimum moisture content attained by the dried seed. After five days of drying at a temperature of 112° F, the moisture approximated 5% while at 107° F it was about 6 5%. It appears that little further desiccation would occur from prolonged exposure at these temperatures. A lot of seed ears dried for 35 days at 107° F contained 4.3% moisture and germinated 98%.

Seed with an initial moisture content up to 30% and reduced to as low as 5% by artificial drying for 5 days at 112° F showed no unfavorable stand or seedling growth effects when planted in the field.

At a drying temperature of 112° F no significant differential injury was found among 26 representative hybrids ranging in moisture content from 16 to 38%. It would seem possible that among hybrids differing greatly in moisture content at the time of drying, those with excessive moisture would be injured. This would not necessarily suggest heritable difference in heat susceptibility, and might be associated solely with moisture content.

THE CARBOHYDRATE-NITROGEN RELATION IN LEGUME SYMBIOSIS[1]

P. W. WILSON AND E. B. FRED[2]

IN a recent issue of this JOURNAL, Allison and Ludwig (2)[3] make a strong plea for retention of their version of the carbohydrate supply hypothesis originally proposed by Mazé (8) and subsequently amended and developed by other workers (5, 7, 10, 12). The ingenious summation of the hypothesis made by Allison (1) possesses an apparent simplicity which recommends it to the consideration of students in this field of research. Nevertheless, the extensive experiments carried out by the authors and their colleagues, together with data from other stations, have led us to the conclusion that the carbohydrate supply hypothesis is inadequate for many aspects of legume symbiosis. Its recent defense contains no new material which would lead to alteration of that conclusion.

At the same time that the views based on the importance of the carbohydrate supply were being developed, rival theories appeared which ascribed the dominant rôle to the nitrogen supply—both inorganic and organic (4, 6, 11). The chief difficulty with both proposals was lack of critical data and especially data from different types of experiments. Almost all of the pertinent tests had dealt with a single method of changing the carbohydrate and nitrogen supply, *viz.*, by addition of combined nitrogen to inoculated leguminous plants. From such experiments it is impossible to separate the effects due to depletion of the carbohydrate from those due to presence of increased nitrogen.

In 1930 research was begun at the Wisconsin Experiment Station which determined the response of several functions of the symbiotic nitrogen fixation system to changes in the supply of carbohydrate and/or nitrogen induced by means other than addition of combined nitrogen. It was only when such data became available that critical examination of the various theories could be undertaken. As a result of this examination it was concluded that both points of view were too limited and circumscribed in their outlook. As is frequently the case, both theories were satisfactory in certain areas of the field, but neither completely sufficed. It appeared that a hypothesis which would take into account the rôle of both carbohydrate and nitrogen would be more satisfactory.

It should be noted that at no time did we favor the carbohydrate supply hypothesis and later abandon it for one based on the relation[4]

[1]Herman Frasch Foundation in Agricultural Chemistry, Paper No. 192, Department of Agricultural Bacteriology, University of Wisconsin, Madison, Wis. Received for publication April 24, 1939.

[2]Associate Professor and Professor of Agricultural Bacteriology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 502.

[4]On the advice of several authorities who are interested in the subject from the point of view of plant physiology we have used the term, *relation*, in general discussion. They point out that it is incorrect to speak of ratios unless a definite ratio is meant; hence, the term carbohydrate-nitrogen ratio is restricted to discussion of specific data and then only when the particular ratio is defined. Also, use of the term, *relation*, should prevent confusion with any particular mechanism associated with a "carbohydrate-nitrogen ratio" theory.

between carbohydrate and nitrogen in the host plant as is suggested by Ludwig and Allison. In our initial publication (3) our position was thus stated,

> "The present paper is concerned with the carbohydrate-nitrogen relation of inoculated leguminous plants, especially as affected by the gaseous environment of the plant and the influence of this relation on nodule formation and nitrogen fixation. The data show a definite correlation between the nitrogen-fixing, photosynthetic and respiratory functions in leguminous plants and afford a common basis for interpretation of problems relating to the following aspects of the fixation process: (a) quantity of nitrogen fixed; (b) size, number and distribution of nodules; (c) effect of combined nitrogen on fixation of free nitrogen."

The essential features and interpretations of the hypothesis, which the following summary shows are neither vague nor complicated, were incorrectly given in the article by Allison and Ludwig. For this reason explicit statement of these will be furnished:

1. Various responses of the symbiotic nitrogen fixation system are regarded as functions of both carbohydrate and nitrogen supply as measured by the relation between them. The particular measure to be used will be discussed later in this paper.
2. If the relation between carbohydrate and nitrogen is such that the supply of the former is the limiting factor, any change in this supply will be reflected in the responses of the fixation system; similarly, with the supply of nitrogen. For example, *invasion of the plant*, as measured by number of nodules, ordinarily is quite responsive to changes in the carbohydrate level as this is the limiting factor. On the other hand, if inoculation of the plants is delayed so that an excess of carbohydrate accumulates, the limiting factor for *development of the nodules* is the supply of nitrogen. Under such circumstances this function of the symbiotic system will be stimulated through addition of combined nitrogen.
3. Even though one of the factors under specified conditions dominates a given response through being the limiting factor, the rôle of the other should not be overlooked. The carbohydrate-nitrogen relation hypothesis regards *at all times* the responses of the symbiotic system as dependent on both carbohydrate and nitrogen supply and thus avoids treating the two cited examples as distinct phenomena with different "causes". In this way the hypothesis provides a consistent, unified, and economical explanation which embraces many different responses of the symbiotic system.

It is emphasized that there is no compulsion about using a carbohydrate-nitrogen ratio as the measure of the relative supply of carbohydrate and nitrogen. Any function of the two which would involve their simultaneous consideration and which could be *conveniently determined* should be equally satisfactory. Because of the use of the ratios in certain fields of both soil microbiology and plant physiology, they appeared to be the logical measures to adopt. Especially to be avoided are interpretations that the relation operates in a mystical

manner. The relation (or specific ratios in actual cases) serves only as a convenient measure of carbohydrate and nitrogen supply; the *mechanism* of its operation is primarily how these affect the plant's functions. For many years soil microbiologists have used the C:N ratio as a convenient indicator of the type of decomposition to be expected, but no one has ever seriously proposed that the term means anything more than the relative supply of energy and structural materials.[5] Certain plant physiologists may have attempted to attribute to the ratios a regulatory influence beyond that of the chemical function of each component, but the view has never met with great approval (9).

Methods for estimation of the relation were discussed and applied to actual cases by Wilson (13). The same ratio could not be expected to be equally satisfactory for all responses since the forms of nitrogen and carbohydrate which are most directly concerned probably vary. The ultimate goal of the biochemical studies is to define exactly the nature of these, but to reach that goal will require much research and likely a better comprehension of general plant metabolism than is now available. In the meantime, it is of interest to determine if valuable correlations can be established between some crude measure of the actual causal factors and certain responses of the symbiotic nitrogen fixation system

Such correlations were discussed by Wilson (13) who employed various ratios for measuring the carbohydrate-nitrogen relation, including total carbohydrate/total nitrogen, total carbohydrate/soluble nitrogen, soluble carbohydrate/total nitrogen, and soluble carbohydrate/soluble nitrogen The use of different ratios was not the result of a haphazard selection but dictated by necessity—in most cases the choice of the measure was determined by the data available. However, the important fact is that for the broad, but nevertheless useful, generalizations which were drawn, any one of the measures appears to be sufficiently accurate. In the few cases in which comparisons were possible among two or more measures and some definite response, it appeared that, usually, the correlations were more obvious and consistent if total carbohydrate/soluble nitrogen was used, but this conclusion is tentative as the data for judgment are quite few. Unfortunately, the necessary chemical determinations which would allow calculation of any one of these ratios have been seldom made so that in the majority of the tests made on the theory the inverse ratio, total nitrogen/dry weight, or *per cent* N, was employed. Although this admittedly is a very crude measure of the factors believed to be responsible, it has the advantage that it is readily, and what is more important, usually is, estimated. In actual practice it has served very well, and until determination of the others become more common, it is likely that it will have to suffice. The chief objection which can be raised against this measure of the relation is that it is probably

[5]The similarity between the carbohydrate-nitrogen hypotheses in soil decompositions and legume symbiosis was the precise feature emphasized in the first extensive discussion of the hypothesis by the senior author. This presentation was made at the symposium on *Decomposition of Organic Matter in the Soil* held in connection with the 1934 meeting of the Society of American Bacteriologists.

only a rough estimate of the real causal factors. Hence, conclusions derived from the hypothesis probably should remain open to revision until more refined data are obtained.

It is evident that there is nothing intangible or vague about estimation of the Ch:N relation provided the trouble is taken to make the required chemical determinations. In this connection the equally important query should be raised, What is the appropriate measure of "carbohydrate supply"? Examination of the literature concerned with this hypothesis reveals that the effects are related to such ill-defined substances as "metabolizable carbon", "available carbohydrate", "carbohydrate delivered to the site of the nodules". No information is provided with reference to the estimation of these supposedly simple, but actually vague, concepts of carbohydrate supply, except that they do not correspond to mere determination of carbohydrate in the plant sap. Until specifications are laid down for determination of the regulatory factor— even if only in a crude manner —it is difficult either to test or to apply the hypothesis.

Consideration of the various terms used to indicate "carbohydrate supply" suggests that this hypothesis implicitly contains that based on the carbohydrate-nitrogen relation. As has been indicated, the important factor appears to be not total carbohydrate but "available carbohydrate", i e., carbohydrate that can be used primarily for energy needs. "Available carbohydrate", then, will be primarily carbohydrate in excess of that required for structural purposes; the latter will depend on nitrogen supply. Hence, in order to obtain a measure of available carbohydrate, it is necessary to use some function which will include consideration of the "available nitrogen." It is suggested that a carbohydrate-nitrogen ratio (which usually can be measured by *per cent* N) is a suitable function to use.

Since Allison and Ludwig, and not ourselves, introduced the interpretation that the ratio as such is the causal agent, it is scarcely necessary to consider in detail the majority of their objections to the carbohydrate-nitrogen hypothesis.[6] In our opinion, the disagreement is largely pointless since it resolves itself into: How large a field is to be covered by a particular hypothesis? Invasion of the plant (number of nodules) is a function of the Ch:N relation in which the limiting factor is primarily supply of carbohydrate. It is not surprising then that the responses of this function can be satisfactorily accounted for entirely on the basis of the carbohydrate supply hypothesis, a fact that was emphasized by Allison and Ludwig who apparently wished to confine the discussion to development of nodules. With other functions, however, the primary attention is focused on the supply

[6]The statement of Allison and Ludwig regarding Wilson's misunderstanding of the top-root ratio hypothesis is in error as is clearly evident by consulting the original paper (13). In the experiments considered by Wilson, the top-root ratio was altered on plants by changes in the length of day, clipping of leaves, temperature, and intensity of light. There is just as much reason to believe that the factor altering the top-root ratio in these plants is the supply of carbohydrates to the roots as when addition of combined nitrogen is followed by a change in this ratio. Nevertheless, such alteration was accompanied by erratic responses with respect to development of nodules; hence, there seems to be no reason for changing the conclusion drawn in the bulletin.

of nitrogen. These include (a) breaking the nitrog (b) use of strains of bacteria of low efficiency, (c) dev dules and initiation of fixation in plants in which inocul delayed, and (d) probably excretion of nitrogen in which gen apparently accumulates from the symbiotic nitro system rather than from an external source. In order to these cases it is not necessary to shift from a hypothesis which s carbohydrate to one which emphasizes the supply of nitrogen. though the plea might be made that these do not represent "norma conditions and hence are not meant to be considered in application o the hypothesis, it must be emphasized that they are not infrequently encountered in actual practice If a hypothesis is to be more than a mere intellectual diversion, it should certainly include consideration of these "exceptions". The Ch.N relation hypothesis, as well as Allison's original version (1) of the carbohydrate supply hypothesis, was offered as a comprehensive explanation of many phases of legume symbiosis and not merely to restricted areas of the field.

SUMMARY

In reply to the criticisms of Allison and Ludwig, advantages of the carbohydrate-nitrogen hypothesis over the carbohydrate supply hypothesis are discussed These include.

1. It combines in a single hypothesis consideration of both supply of nitrogen and of carbohydrate and thus replaces both It is pointed out that the carbohydrate supply hypothesis itself implies that the proper measure is the relation between carbohydrate and nitrogen rather than carbohydrate alone. A leguminous plant, by reason of the nitrogen fixation system in the nodules, exercises some internal control over its nitrogen supply independent of what the experimenter does with the external source of combined nitrogen. For this reason, it is believed that photosynthesis and nitrogen fixation must be considered as interrelated processes and that the function of one should not be emphasized at the expense of the other. In some cases the supply of carbohydrate is the dominant factor, but in others the reverse is true. When the supply of nitrogen rather than carbohydrate is the effective agent, interpretation in terms of carbohydrate supply becomes artificial.
2. The Ch:N relation has several definite measures of varying degrees of refinement, whereas the carbohydrate supply hypothesis has, in the past, employed such concepts as "available carbohydrate" and "metabolizable carbon" without specifying methods for their estimation. Moreover, even if the usual measures of carbohydrate supply, as *total* or *soluble* carbohydrate, are employed as a crude estimate of the "available carbohydrate", the determination is much less a routine operation with most workers than is the corresponding measure of Ch:N relation (*per cent* N). For this reason the hypothesis based on the relation can be more readily extended and applied to practice.

Our own experience has led us to the conclusion that it is an avoidable oversimplification to consider carbohydrate supply as the pri-

mary factor in legume symbiosis and to relegate the supply of nitrogen to a secondary rôle of serving as one method for control of carbohydrate. However, we do not consider the question of which hypothesis is "true" as a very critical one. The major requirement at this time for advancement in understanding of the biochemistry of legume symbiosis is experimental facts. If any hypothesis suggests means for obtaining these facts, its use will be justified irrespective of final judgment as to its validity. There are yet numerous questions to be answered relative to the importance of both nitrogen and carbohydrate in legume symbiosis; it is suggested that energy directed towards securing the much-needed quantitative data would be much more profitably expended than in fruitless controversy.

LITERATURE CITED

1. ALLISON, F. E. Carbohydrate supply as a primary factor in legume symbiosis. Soil Science 39:123–143. 1936.
2. ———— and LUDWIG, C. A. Legume nodule development in relation to available energy supply. Jour. Amer. Soc. Agron., 31:149–158. 1939.
3. FRED, E. B., and WILSON, P. W. On photosynthesis and free nitrogen assimilation by leguminous plants. Nat. Acad. Sci. Proc., 20:403–409. 1934.
4. GIÖBEL, G. Relation of soil nitrogen to nodule development and nitrogen fixation by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1926.
5. HOPKINS, E. W., and FRED, E. B. Influence of various nitrogenous compounds and mannitol on nodule formation by clover. Plant Physiol., 8:141–155. 1933.
6. LAURENT, É. Recherches sur les nodosités radicales des Légumineuses. Ann. Inst. Pasteur, 5:105–139. 1891.
7. LEONARD, L. T. Relation of photosynthetic carbohydrate activity to nodule formation on soybeans. Jour. Amer. Soc. Agron., 18:1012–1016. 1926.
8. MAZÉ, M. Les microbes des nodosités des Légumineuses. Ann. Inst. Pasteur, 12:128–155. 1898.
9. NIGHTINGALE, G. T. The nitrogen nutrition of green plants. Bot. Rev., 3:85–174. 1937.
10. RÜFFER, E. Forschungen zum Kohlenhydratumsatz bei Knollchentragenden und Knollchenfreien Sojabohnen. Ztschr. Pflanzenernahr. Dungung, A *24:* 129–167. 1932.
11. STROWD, W. H. Relation of nitrate to nodule production. Soil Science, 10: 343–356. 1920.
12. WEBER, E. Saltpeterdungung als Beeintrachtigung der Stickstoffsammlung durch Leguminosen. Centbl. Bakt. (etc.) 2 Abt., 82:353–379. 1930.
13. WILSON, P. W. The carbohydrate-nitrogen relation in symbiotic nitrogen fixation. Wis. Agr. Exp. Sta. Res. Bul. 129. 1935.

STUDIES OF BORON DEFICIENCY IN IDAHO[1]

William E. Colwell and G. Orien Baker[2]

BORON has been termed a "minor element" because of its requirement in relatively small quantities, but according to Nafter (8)[3] it could be considered a major element from the standpoint of plant nutrition.

Although the necessity of boron in plant growth was discovered by Maze in 1914, it was in 1931 that Brandenburg directed the attention of agriculturists to its use as an artificial fertilizer by showing that under field conditions its deficiency was the cause of heart rot and dry rot in sugar beets.

As far as it is known, the first record of boron deficiency under field conditions in the United States was in Maryland where it was found to produce characteristic symptoms on tobacco plants. This was reported in 1935 by McMurtrey (7) From 1936 to 1938 the fertilizer action of boron was being recognized, and during this period approximately 350 investigations were reported (8). Investigators in many states, including Alabama, California, Connecticut, Florida, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, South Carolina, Vermont, Washington, and Wisconsin, have to date reported response to boron fertilization.

Several excellent reviews of the literature and relatively complete lists of references dealing with the effects of boron on several plants have been compiled by Dennis (3), Dennis and O'Brien (4), Willis (10), and by the American Potash Institute (1).

In 1936, McLarty (5) in Canada showed that boron was the substance effective in preventing drought spot and corky core in apples. Further work in Canada by McLarty, Wilcox, and Woodbridge (6) showed that a certain type of alfalfa yellowing was caused by a lack of boron and that it could be overcome by the addition of either boric acid or borax.

These investigations called attention to the possibility of a similar problem in northern Idaho, for it had been noted for a number of years that certain fields of alfalfa in that area were showing a similar yellowing.

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[3]Figures in parenthesis refer to "Literature Cited", p. 512.

PLAN OF GREENHOUSE EXPERIMENTS

The purpose of the greenhouse investigations was to supplement the field method of determining probable boron deficiency in soils, since the field method is both time-consuming and costly. Five plants were produced in 1 pound of the soil to be tested and all the elements required for normal plant growth, except boron, were added either in a nutrient solution or directly to the soil. The boron must then be supplied by the soil itself. Several cans containing acid-washed quartz sand were included in each experiment for the purpose of checking against boron contamination in the nutrient solution.

The containers used were commercial "No. 1 tall renameled charcoal" cans. The enamel was not destroyed during the growing period so the danger of boron contamination was greatly reduced. The soil was transferred to a new can when a second crop was grown in a soil which had already produced one crop.

Ten sunflower seeds were planted per can and when well established they were thinned to five uniform plants. During early stages of growth, nutrient solution was added alternately with distilled water to keep the moisture content at normal field capacity. Later, when transpiration losses were great, a maximum of 25 cc of nutrient solution were added each day and distilled water was used as often as necessary to keep the moisture content fairly constant. About 30 applications of nutrient solution were made throughout the period of growth. Determinations of soluble salt content in the soils before and after the growing period indicated that their concentration had been increased and in many soils had become quite high. Although no detrimental effects of too high a salt concentration were noted, it seems advisable to reduce the applications of nutrient solution to a minimum. Determinations of pH on the soils before and after the growing period showed no significant change.

Each liter of nutrient solution used contained the indicated number of cc's of each of the following molar solutions: 5 cc KH_2PO_4, 2 cc K_2HPO_4,[4] 7 cc $MgSO_4$, 7 cc $Ca(NO_3)_2$, 7 cc $NaNO_3$.[5]

Manganese sulfate to supply the equivalent of 5 pounds of manganese per acre was added separately to the soil of each can. Boric acid to supply the equivalent of 5 pounds of boron per acre was added to those receiving the complete nutrient solution plus boron.

RESULTS OF GREENHOUSE INVESTIGATIONS

INDICATOR PLANTS

A comparison of tobacco, nasturtiums, sugar beets, and sunflowers was made in an attempt to find which plant would be the most sensitive indicator of boron deficiency. In each case characteristic boron deficiency symptoms developed on the sunflowers sooner than on any of the other three test plants. A pronounced decrease in flowering was noted in the nasturtiums growing in soils receiving no boron,

[4]The stock solution of K_2HPO_4 being used at the present time is only 1/5 molar.

[5]A comparison of two nutrient solutions differing in concentration of nitrogen was made. One contained 7 cc molar $Ca(NO_3)_2$ per liter of solution and supplied 196 p.p.m. of N. The other contained 7 cc molar $Ca(NO_3)_2$ per liter and 14 cc molar $NaNO_3$ per liter, supplying a total of 392 p.p.m. of N. In each case boron deficiency symptoms became apparent from 1 to 8 days earlier on the sunflowers receiving the latter solution. Some soils, however, may have reacted unfavorably to the high concentration of sodium, so in order to avoid danger from this cause the solution finally used was the above.

but this was only apparent some time after the s[illegible] de-veloped definite deficiency symptoms. Tobacco [illegible] growing in soils receiving no boron each develop[illegible] symptoms but only after a relatively long growing pe[illegible]

Besides producing definite symptoms of boron defic[illegible] early stages of growth, sunflowers are easily handled in the [illegible] house. They are readily started and require no means o[illegible] during even the later growing period. As a result of these [illegible]tions they were used as test plants throughout the remainder of [illegible] investigation.

BORON DEFICIENCY SYMPTOMS OF SUNFLOWERS

The first sign of boron deficiency is a yellowing at the base of the young leaves of the growing tip. Soon the entire area of the young leaf turns yellow, then almost white, and dies. The older leaves nearest the growing point begin to yellow at the base and become thickened and drawn and show a tendency to roll in a half circle with the tip pointing toward the stem (Fig. 1). These deformed leaves are a shiny green at the end and shade from yellow to reddish brown at the base. This condition is followed by a drooping of the older leaves and a shortening of the internodes, giving a "rosetted" appearance. The leaves of the flattened top of the plant may be thick and brittle. Necrosis of the terminal growth takes place rapidly and in severe cases the entire center becomes a reddish brown color. If the plant is allowed to grow, the older leaves continue to die until finally a woody stalk bearing drooping, nearly dead leaves is all that remains. In less severe cases the yellowing of the young leaves is not followed by immediate death of the terminal growth but by a mosaic pattern of five or six of the older top leaves. Later these yellow areas, sometimes occurring over the entire surface of the older leaves, have a reddish tinge. Depending on the severity of the case, the younger leaves may or may not thicken, curl downward, and die.

BORON DEFICIENCY AS INDICATED BY ROOT DEVELOPMENT

Although the difference in root size caused by the addition of boron to boron-deficient soils is not a practical means of determining whether or not a soil is deficient in boron, the stimulating effect of boron upon root development is worth mentioning. The difference is shown in Fig. 2. The five roots shown in the upper half of the figure were cut from those plants receiving boric acid at the rate of 5 pounds of boron per acre and those shown in the lower half had received no boron. An even greater difference was noted in the roots from the second foot of the same soil. It has been a common observation throughout the greenhouse studies that the symptoms became apparent first in plants grown in the second foot samples. This difference is shown in Table 1.

EFFECT OF PRODUCING A SECOND CROP IN A SOIL WITHOUT BORON ADDITIONS

After the sunflowers, growing in the first foot of soil, were harvested, four of the soils tested were transferred to new cans and sunflowers

TABLE 1.—*Oven-dry weight of sunflower tops per can and days required to produce first boron deficiency symptoms.**

Soil type	First crop						Second crop first foot	
	First foot			Second foot				
	Days	Check —B, grams	Boron +B, grams	Days	Check —B, grams	Boron +B, grams	Days	Without boron, grams
Quartz sand (check)	19	1.17	4.90	—	—	—	—	—
Springdale coarse sandy loam	26	2.81	7.07	—	—	—	25	1.85
Santa silt loam	31	5.15	8.19	29	3.99	7.54	—	—
Garrison gravelly loam	33	7.11	7.70	—	—	—	32	3.47
Bonner fine sandy loam	36	6.84	8.34	—	—	—	25	3.77
Mission silt loam	38	6.73	9.07	37	6.19	7.43	38	5.53
Helmer silt loam	42	4.57	6.09	35	2.75	5.94	—	—
Moscow loam	42	5.15	5.28	37	3.62	4.80	—	—
Springdale gravelly loam	45	7.43	9.97	39	3.82	6.39	19	0.74
Palouse silt loam	50	7.09	8.73	61	4.86	5.15	—	—

*All first crop data are averages of duplicates and all plants were harvested after 53 days except those growing in quartz sand, Sprindale gravelly loam, and Palouse silt loam which were harvested after 61 days. The sunflowers grown in quartz sand and Springdale gravelly loam were planted on March 15, 1938, while all the others were planted on May 7, 1938. All second crop data are single determinations.

were seeded again. This is referred to as the second crop. At the same time, some of the original of each soil was placed in cans and planted. Boric acid to supply 5 pounds of boron per acre was added to half of

FIG. 1.—Sunflower plants 40 days old growing in Garrison gravelly loam to which all the elements essential for plant growth except boron had been added. Note the dead center of each of the five plants and the drooping of some of the older top leaves.

the new samples and the others served as checks. The growth obtained from the first foot of soil with and without boron and for the second crop without boron on Bonner fine sandy loam is shown in Fig. 3.

FIG 2 —Sunflower roots grown in the first foot of Springdale gravelly loam with boron (upper) and without boron (lower) ¾ actual size

It may be observed from Table 1 and Fig 4 that sunflowers growing on the second foot of soil develop deficiency symptoms somewhat sooner and make smaller growth than those plants grown in the first foot. It may also be observed that the second crop of sunflowers

grown in boron-deficient soils produce deficiency symptoms somewhat sooner and produce a smaller yield than the first crop grown. This may indicate that most of the available boron has been used by the first crop and that the process of more boron becoming available is too slow to meet the crop requirement. This result is confirmed by field observations where it is noted in most instances in northern Idaho that the second cutting of alfalfa is more seriously affected by yellowing than the first.

FIG 3.—Sunflowers growing in a sample of the first foot of Bonner fine sandy loam The treatments are, from left to right, boric acid added at the rate of 5 pounds of boron per acre, no boron added, and the second crop produced by this pound of soil without boron addition for either crop.

FIELD INVESTIGATIONS

In order to correlate the greenhouse results with those obtained in the field, tests were established in northern Idaho on alfalfa which had shown yellowing the year before Two tests on different soils, Springdale coarse sandy loam gravelly phase and Helmer silt loam, were designed to compare fall with spring application and also rates of application. In each case, 20, 40, and 60 pounds of borax per acre were applied to 1/20 acre plats in November 1937 and April 1938. The material was mixed with dry sand to add bulk and was broadcast.

Observations made the middle of June just before the first cutting indicated that fall applications were more effective than spring; also that, in the case of the coarser textured soil, a 20-pound application in the fall was insufficient. No yellowing was observed in plats receiving 40 and 60 pounds per acre of borax either in the fall or 60 pounds per acre of borax in the spring. Smaller applications of 18 to 20 pounds of borax per acre on sugar beets have been used with good results by German and Irish workers and, although the rates used in this investigation are higher than those generally used and recommended, no indications of toxicity were noted on the treated plats. Attention has recently been called, however, to the beneficial results obtained from the use of boric acid on alfalfa at the rate of 40 pounds per acre (9).

The increased growth resulting from the addition of borax to alfalfa is shown in Fig. 5 which represents two individual plants grown on a Springdale soil. The untreated plant did not have another plant closer than 3 feet, while the one treated with 60 pounds of borax per acre had three plants within a 1-foot radius. The plant from the check plat was very yellow and the blossom buds were aborted or very small and deformed. On the other hand, the plant from the treated plat was dark green in color and the blossom buds were large and normal.

In the spring of 1937, 10 tests on five soil series were started, using borax at the rate of 40 pounds per acre. June observations before the

first cutting showed a distinct visual difference in seven cases, while in three cases no difference could be observed.

Unfortunately, it was impossible to visit all the tests at the time of the second cutting, but the few observed showed even greater differences than did those which were observed when the first cutting was made This correlates with the farmers' observations that the second crop is more seriously affected by the yellowing than the first.

FIG 4 —Sunflowers growing in a first and a second foot sample of uncultivated Santa silt loam

DISCUSSION

It appears from this preliminary study that many of the soils of northern Idaho are deficient in available boron for alfalfa. This may be the result of climatic factors, soil development processes, and character of parent materials, all of which had some influence in the formation of these soils.

The mineral tourmaline, which is the most common boron-carrying mineral, is known to occur only in very small quantities in the basalt and the sedimentary strata which underlie most of northern Idaho. Therefore, the material which is a major constituent of the parent material of both glacial and loessial soils of this area would appear to be inherently low in boron.

Tourmaline, however, is known to be quite abundant in the granitic intrusive rocks and in the older sedimentary rocks altered by emanations from the igneous magmas. These materials, however, do not occur in great quantities in the parent material of soils in northern Idaho.[6]

The data show that under the condition tested the sunflower exhibits symptoms of boron deficiency much sooner than either the tobacco, nasturtium, or the sugar beet. Furthermore, the appearance

[6]Personal communication from Dr. A. L. Anderson, Department of Geology, University of Idaho.

of definite and recognizable symptoms offers a more sensitive means of detecting a boron-deficient soil than do differences in weight or in root development between healthy and diseased plants

FIG 5 —Individual alfalfa plants grown on Springdale coarse sandy loam gravelly phase (A) From plat receiving borax at rate of 60 pounds per acre, (B) from check plat receiving no borax Note the yellowed leaves and stunted growth of the plant which had not received borax

It was observed that sunflowers growing in samples of the same soil developed boron deficiency symptoms from one to eight days sooner when a nutrient solution relatively high in nitrate nitrogen was used. Whether this is due to a more luxuriant vegetative growth or whether it is an indication that the function of boron is in some way related to the regulation of nitrate ion absorption or nitrogen metabolism is not known.

Those plants growing in coarse-textured soils deficient in boron developed symptoms of severe deficiency soon after the first recognizable symptoms appeared. In a very few days after this, sometimes only three or four, those plants suffering from a lack of boron were practically dead. Those plants growing in the finer-textured soils often did not develop severe symptoms of the deficiency, and death did not occur in plants growing in any of the fine-textured soils under investigation.

Samples of alfalfa, some showing yellowing and some healthy plants, were analyzed for boron, and a lower content was found in the yellowed plants. Too few samples were analyzed, however, to state definitely that this relationship always exists under northern Idaho conditions.

SUMMARY

1. A greenhouse method suitable to detect boron-deficient soils is described. A good correlation was obtained between greenhouse and field experiments.

2. Preliminary field tests in northern Idaho indicate that fall applications of borax at the rate of 40 to 60 pounds per acre are superior to spring applications in overcoming yellowing in alfalfa.

3. The results of a limited number of analyses on alfalfa indicate that a high boron content of alfalfa is associated with freedom from yellowing.

4. The investigations are of preliminary character. Further work is being done to substantiate these findings.

LITERATURE CITED

1. AMERICAN POTASH INSTITUTE. Boron as a plant nutrient. 1938.
2. ANONYMOUS. Boron and plant life. Fertilizer, Feeding Stuffs and Farm Supplies Jour., Dec. 4 and 18, 1935; Jan. 1 and 29, 1936.
3. DENNIS, R. W. G. Boron and plant life, II: Recent developments in agriculture and horticulture. Fertilizer, Feeding Stuffs and Farm Supplies Jour., Sept. 8 and 22; Oct. 6, and 20, 1937.
4. ———— and O'BRIEN, D. G. Boron in agriculture. West of Scotland Agr. Col. Res. Bul. 5:1. 1937.
5. MCLARTY, H. R. Tree injections with boron and other materials as a control for drought spot and corky core of apple. Sci. Agr., 16:625 633. 1936.
6. ————, WILCOX, J. C., and WOODBRIDGE, C. G. A yellowing of alfalfa due to boron deficiency. Sci. Agr., 17:515–517. 1937.
7. MCMURTREY, J. E., Jr. Boron deficiency in tobacco under field conditions. Jour. Amer. Soc. Agron., 27:271–273. 1935.
8. NAFTEL, JAMES A. Recent studies on boron in soils. Amer. Fert., 89:No. 7. Oct., 1938.
9. POWERS, W. L. The minor elements in soil fertility and plant nutrition. Ore. State Agr. Col., Sta. Circ. of Information No. 192. 1938.
10. WILLIS, L. G. Bibliography of references to the literature on the minor elements and their relation to the science of plant nutrition. New York: Chilean Nitrate Educational Bureau. Ed. 1, 1935; Ed. 2, 1936; Ed. 3, 1939.

THE DIFFERENTIAL RESPONSE OF ALFALFA VARIETIES TO TIME OF CUTTING[1]

H. M. TYSDAL AND T. A. KIESSELBACH[2]

THAT alfalfa responds adversely to too frequent cutting has been rather thoroughly demonstrated in numerous experimental tests. The comparative reaction of different varieties has not been studied to a similar extent, however, and the response of the comparatively new variety Ladak has, as yet, not been reported. Since this variety has shown a rather strikingly different response to cutting treatment, the present report has been prepared showing its yield and stand in comparision with three standard varieties under several cutting treatments during the past five years at the Nebraska Experiment Station.

As a preliminary comparison, Table 1 is presented giving a summary of the yield and maturity at time of cutting Ladak compared to Grimm and Nebraska Common in a number of field plat varietal tests conducted during the period 1929 to 1933. These tests were on two different fields, and considering the number of replications and years involved, averages of 29 different plat yields of each variety are reported in the table. The actual and relative yields are given by cuttings. The cutting treatment in these variety tests may be considered approximately normal for standard varieties for this locality, the first cutting being taken about June 1, the second during the first 10 days of July, and the third usually more than a month later. In general, the Ladak yielded proportionately more than Grimm or Nebraska Common in the first cutting, 57% of the total crop being produced in the first cutting compared with 49% for Grimm and Nebraska Common. Ladak yielded both actually and proportionately less than the other varieties in the second and third cuttings. The high yield of Ladak in the first cutting suggests that it may be a very desirable variety under those conditions where one cutting constitutes the total hay crop. This particular adaptation has been mentioned in other reports.[3]

The maturity at the time of cutting as indicated by the percentage of bloom, shows that Ladak is more immature at the second and third cutting under these conditions of harvest than the other two varieties although there is not much difference in the first cutting.

TIME-OF-CUTTING EXPERIMENT

In August, 1932, a new set of field plats was sown to four varieties—

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[3]WESTOVER, H. L. Alfalfa varieties in the United States. U. S. D. A. Farmers' Bul. 1731. 1934.

TABLE 1.—*Mean annual yield per acre from the various cuttings of Ladak, Grimm, and Nebraska Common alfalfa, and the stage of maturity at time of cutting as compiled from two variety tests during four years, 1929–1933.*

Cutting	Grimm	Nebr. Common	Ladak
	Tons Per Acre by Cuttings, 15% Moisture		
1st	1.67	1.57	1.96
2nd	1.10	1.00	0.98
3rd	0.63	0.60	0.52
Total	3.40	3.17	3.46
	Relative Yield by Cuttings, Total for Season = 100		
1st	49	49	57
2nd	32	32	28
3rd	19	19	15
Total	100	100	100
	Maturity at Time of Cutting as Indicated by Per cent Bloom		
1st	7	3	8
2nd	67	52	46
3rd	58	49	39
Average	44	35	31

Grimm, Nebraska Common, Hardistan, and Ladak, each replicated 24 times. In 1933 all plats were cut at the same time, the first cutting not being taken until June 21, the second July 29, and the third September 6. These dates constitute much later cuttings than normal and in Table 2 these are referred to as "late" cutting, with respect both to the date of the first cutting and the intervals between cuttings.

In 1934 these replicate plats were grouped for cutting at two stages of maturity. Five plats of each variety, designated as "early" cutting (Table 2) were cut on the successive dates of May 17, June 16, and July 10. The remaining plats, 17 of each variety, were cut June 7 and July 6, designated as "medium" cutting. The field was in its prime and despite the severe drought yielded an average of more than 3 tons of cured hay per acre in two cuttings. In all treatments Grimm and Nebraska Common responded very similarly and there was no significant difference in their yields as calculated from a generalized error by variance.

On the other hand, in 1933, with the late cutting treatment, Ladak yielded 108% of Grimm which is significantly higher. In the medium cutting treatment in 1934 it yielded about the same as Grimm, but in the early cutting treatment of 1934 it yielded only 83% as much as Grimm, an amount very significantly lower than Grimm or Nebraska Common.

In 1935 the plats were again cut at different times, some of them being cut twice, some three times, and some four times. In no case were there less than three replicates of each variety or more than seven. The yields from these cuttings are also given in Table 2, together with the dates of cutting. In all of the late and medium-late

TABLE 2.—*Comparative yields of four alfalfa varieties cut at different dates during the years 1933–35.*

Time of cutting	Year	Actual yield, tons per acre: Grimm	Actual yield, tons per acre: N. W. Nebr. Common	Actual yield, tons per acre: Hardistan	Actual yield, tons per acre: Ladak	Difference for significance, tons	Yield relative to Grimm: Grimm	Yield relative to Grimm: N. W. Nebr. Common	Yield relative to Grimm: Hardistan	Yield relative to Grimm: Ladak
Late[1]	1933	2.56	2.61	2.60	*2.76*[9]	0.07	100	102	102	108
Medium[2]	1934	3.21	3.22	*3.15*	*3.15*	0.05	100	100	98	98
Early[3]	1934	3.35	3.42	3.29	*2.79*	0.12	100	102	98	83
Late[4]	1935	3.20	3.06	*2.94*	3.31	0.22	100	96	92	103
Late[5]	1935	2.73	2.68	2.68	2.92	0.22	100	98	98	107
Medium late[6]	1935	2.81	2.70	2.82	*3.24*	0.14	100	96	100	115
Early[7]	1935	2.88	2.79	*2.67*	*2.69*	0.16	100	97	93	93
Early[8]	1935	3.10	3.15	*2.87*	*2.78*	0.22	100	102	93	90

[1]Late cuttings made June 21, July 29, and Sept 6, 1933.
[2]Medium cuttings made June 7 and July 6, 1934
[3]Early cuttings made May 17, June 16, and July 10, 1934
[4]Cuttings made June 24, August 2, and Sept 10, 1935
[5]Cuttings made June 24 and August 2, 1935.
[6]Cuttings made June 12 and July 12, 1935.
[7]Cuttings made June 3, June 25, and July 25, 1935
[8]Cuttings made June 3, June 25, Aug 2, and Sept. 10, 1935
[9]The yields which are significantly different from Grimm appear in italic.

cuttings Ladak is the highest-yielding variety, whereas when the varieties were cut early it is lowest when four cuttings were taken and next to the lowest with three cuttings, in both cases being significantly lower than Grimm.

Thus, in the same group of plats, Ladak is the highest-yielding variety under one cutting treatment, while under another it is the lowest.

YIELD BY CUTTINGS

With reference to the production in different cuttings of the same year it can be seen from Table 3 that Ladak responds very differently from the other varieties, depending not only on the time of the first cutting but also on the interval between cuttings. For example, when harvested at an early stage throughout the season, Ladak produced very little more than Grimm in the first cutting and very much less than Grimm in the second cutting. The difference was usually even greater in the third cutting. On the other hand, by leaving the first cutting late the Ladak increased its advantage over Grimm, in this instance to 0.37 ton per acre or 22%, and if a rather long interval was allowed to elapse before the second cutting was taken Ladak yielded almost as much as Grimm. This was also true of the third cutting. For example, in the third cutting of 1933 when a relatively long interval was left between the second and third cuttings, Ladak produced as much as Grimm The usual interval between cuttings may be considered approximately one month in this territory, and a relatively long interval would be 40 days or more, this depending however on a large number of factors. From observation it is apparent that Ladak starts growth much more slowly than Grimm after cutting, but from results of delayed cutting it appears that once it does start it grows more rapidly than Grimm, particularly as it approaches the harvest stage. It also appears that Ladak retains its leaves somewhat longer than the other three varieties as it approaches maturity due to its greater leaf-spot resistance and possibly other factors, thus maintaining its hay quality relatively better in the more mature stages.

TABLE 3 — *Yield, in tons per acre, of Ladak and Grimm alfalfa in the first and second cuttings as influenced by time of cutting, average of 1934 and 1935 crops.*

Time of cutting*	Yield, tons per acre (15% moisture)					
	1st cutting			2nd cutting		
	Grimm	Ladak	Difference in favor of Ladak	Grimm	Ladak	Difference in favor of Grimm
Early ..	1.44	1.54	0.10	1.01	0.71	0.30
Medium....	1.73	2.04	0.31	1.29	1.16	0.13
Late	1.65	2.02	0.37	1.14	1.03	0.11

*Applies to both first and second cuttings.

MATURITY AT TIME OF CUTTING

At the time of cutting the various plats the estimated percentage bloom was recorded, considering full bloom as 100%. Tables 1 and 4 show that Ladak was about as mature in the first cutting as any other variety, whether cut early or late, but in the second and third cuttings Ladak usually was far behind in percentage of bloom Even when an unusually long time elapsed between cuttings Ladak did not approach the maturity of Grimm In the second cutting of 1935, with a medium interval between cuttings, Ladak had an average percentage bloom of only 18, while Grimm had 61% bloom In the third cutting of 1933 which was exceptional in that Ladak yielded practically the same as Grimm, the latter had 16% bloom, while Ladak had only 5% bloom. Of the four varieties under consideration, Grimm generally has the most profuse bloom, Nebraska Common second, and then Ladak or Hardistan depending on the cutting Hardistan usually has less profuse bloom than any of the other varieties in the first cutting, but usually blooms somewhat more than Ladak in the second and third cuttings.

TABLE 4 - *Maturity at time of cutting four alfalfa varieties as indicated by percentage of bloom, 1935.*

Time of cutting*	Percentage bloom at							
	1st cutting				2nd cutting			
	Grimm	N W Nebr Common	Hardistan	Ladak	Grimm	N W Nebr Common	Hardistan	Ladak
Early	2	1	0	2	0	0	0	0
Medium	14	11	4	8	61	41	36	18
Late	69	58	40	65	-†	†	†	-†

*Same dates as in Table 2

†Estimate of percentage bloom not possible because of blasting of buds

EFFECT OF CUTTING TREATMENT ON STAND SURVIVAL

One of the important questions relating to time of cutting is that of stand survival. While it is not the purpose of this paper to report in detail the influence of cutting on stand, certain stand counts were obtained which might prove of interest. In the fall of 1938 the plats whose yields are reported in Table 2 were plowed and at this time counts were made of the plants occurring in a strip 2 inches wide along the edge of a furrow extending across the plats. From 8 to 10 such counts were made on each plat, and since there were at least three plats of each treatment the average counts reported in Table 5 are the average of approximately 27 determinations The stands per acre are reported in thousands, and a significant difference in the readings was calculated by the variance method to be 54 (000).

While the stands, on the whole, were very good at the end of the six-year period, some of the plats with the lowest stand count were beginning to thin and were given estimated stands of less than 90%.

The interesting feature of Table 5 is the difference shown in the response of the varieties. Ladak and Hardistan, both somewhat more cold resistant and wilt resistant than Grimm or Nebraska Common, do not show a significant difference in stand count between the early, frequent cutting treatment and the late cutting treatment. Both Grimm and Nebraska Common show a significant difference between these treatments. Ladak shows a significant difference between the first cutting early treatment and the late cutting treatment, which might indicate that Ladak is somewhat handicapped when it has the first cutting, which is normally its largest cutting, taken off prematurely. Nebraska Common is the only variety which has a significant difference between the early cutting treatment and the first cutting early treatment, which may again point out the greater susceptibility of this variety to severe cutting treatments.

TABLE 5.—*Stand counts of plants per acre made in 1938 on plats planted in 1932 and subjected to different cutting treatments from 1933 to 1937, inclusive.*

Time of cutting	Thousands plants per acre*			
	Grimm	Nebraska Common	Hardistan	Ladak
Early throughout	352	324	437	426
First cutting early, others medium	386	393	437	400
Medium	399	405	459	432
Late	435	424	471	470

*Difference necessary for statistical significance between any two readings = 54 (000)

CONCLUSIONS

The response of Ladak to different times of cutting is so great that it may almost be said that this variety can be made the lowest or highest yielding in a series of standard varieties through change in the time of cutting. In these experiments, when the first cutting was late and subsequent cuttings had a relatively long time to develop, Ladak was significantly higher in yield than any of the other three varieties tested. When it was cut unusually early it was significantly lower in yield than Grimm in all comparisons, and equally low or significantly lower than the other varieties, Nebraska Common and Hardistan.

In contrast to this, Nebraska Common was not significantly different in yield from Grimm under any cutting treatment and Hardistan reacted rather similarly to Grimm, although somewhat lower in yield under some treatments than others. Early cutting appears to handicap Hardistan slightly in comparison to Grimm.

The logical question arising from these results is whether it is necessary to harvest varieties at different times in an ordinary variety test to secure accurate comparisons, and, if so, what criteria are going to determine the time of cutting. While it is not the purpose of this paper to go into this question fully, it seems desirable that in at least some varietal tests adequate attempts be made to obtain a knowledge of cutting treatments for optimum production of different varieties.

The exact criteria as to when to cut the varieties for optimum production is a more difficult question. While the percentage bloom is of some value as an index to stage of maturity, it is subject to so many factors, both ecological and physiological, that it is often impossible to judge the relative maturity of varieties by this method. For example, Ladak and Hardistan seldom bloom as profusely in late summer as Grimm or Common in this territory; hence if Grimm were left to a medium percentage bloom before cutting, it is unlikely that the former two varieties would reach a similar degree of bloom. Often the time to cut is determined by the beginning of new growth at the crown. While it has been observed that Ladak starts growth more slowly from the crown, which would correlate with the desired delayed cutting practice, insufficient data are available to indicate whether this would make a reliable criterion.

Since it is so difficult to judge exact maturity in alfalfa varieties, it is suggested that a desirable practice might be to plan certain tests so that replicate plats could be harvested at different intervals, all of the varieties being cut at the medium-early stage, for example, while another group of plats would be cut at a later stage throughout. In this way a correct rating of the varieties could be obtained, and in addition proper recommendations for the commercial handling of the crop could be made The results of this study indicate, for example, that, barring the intrusion of certain disease and insect pests, Ladak should be allowed to grow somewhat longer for the first cutting and between subsequent cuttings than is usually the case with Grimm or Common for optimum production either in variety tests or on the farm.

THE RESPONSE OF LESPEDEZA TO LIME AND FERTILIZER[1]

R. E. STITT[2]

THE annual lespedezas have become established as hay, pasture, and soil-improvement crops in many of the southern states. The general experience of farmers with the annual varieties of common lespedeza (*Lespedeza striata*) (*Thunb.*) *H* & A.) and Korean (*L. stipulacea* Maxim.) and the perennial sericea (*L. sericea* (Thunb.) Benth.) has shown that they are adapted to soils on which other legumes will not grow without considerable expense for lime and fertilizer. Although the lespedezas will grow on so-called poor soils there is some evidence indicating that the use of fertilizers under certain conditions may be beneficial.

In pot experiments, Hyland (5)[3] studied the growth of Korean and sericea lespedezas as compared with red clover and sweet clover on four acid soil types in which the pH was raised to different levels by applying calcium carbonate. Sericea was slightly more tolerant of higher acidity than Korean lespedeza. Soil pH readings were not true indicators of the adaptation of any of the legumes to the soils studied.

In west Tennessee Essary (2) reports increases in yield of common lespedeza from the use of lime but commercial fertilizers did not influence yields to an appreciable extent.

Blair (1) in North Carolina reports the average yield of four different varieties of lespedeza on an Alamance gravelly silt loam to be higher with lime and superphosphate treatments than on the untreated plats.

Pieper, *et al.* (7), in southern Illinois, increased the yield of Korean lespedeza on several soils with applications of limestone and crop residues and also concluded that some soils need phosphate for lespedeza.

In Missouri the yield of Korean lespedeza was increased with superphosphate but decreased with application of 3 tons of lime according to Etheridge, *et al.* (3).

On a Berks shale soil in Virginia, Gish and Hutcheson (4) increased the yield of Korean lespedeza with both lime and superphosphate.

At the Kentucky Agricultural Experiment Station (6) analyses were made of 34 lespedeza hay samples and found that all from poorer soils were low in phosphorus. Lime and phosphates increased hay yields on a sandstone soil at the western Kentucky substation, however, no increased growth was found with lime and fertilizer treatments on a limestone soil.

These few experimental results over a widespread area indicate that lime and phosphates may be beneficial to lespedeza on some soil types. Previous fertilizer treatment and the type of rotation seem not to have been considered in these experiments which raises the question of the desirability of applying fertilizer to lespedeza when fertilizer has been used with other crops in the rotation. The first experiment

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[3]Figures in parenthesis refer to "Literature Cited", p. 527.

herein reported was conducted in order to determine this point more fully and the second in order to determine the effect of fertility level on the different varieties of lespedeza.

LESPEDEZA IN ROTATION WITH FERTILIZED CROPS ON A FERTILE SOIL

The effect of lime and fertilizer on Korean and Kobe lespedeza when grown in an oat-lespedeza rotation on a Cecil loam was studied in an experiment conducted during 1931 at Statesville, North Carolina. The field on which the experiment was conducted had not previously received lime, but applications of a complete fertilizer had been made to crops in previous years including 1930 when oats was grown. Plats on which lespedeza was grown in 1931 were laid out in triplicate on two areas on this field, one area receiving no lime and the other one ton of limestone per acre. The fertilizer treatments for the lespedeza plats were 400 pounds of 2–10–4,[4] 200 pounds of superphosphate containing 16% phosphoric acid, 100 pounds manure salts containing 20% potash and 500 pounds of basic slag containing 8% phosphoric acid per acre.

The results of the different treatments are shown in the hay yields from these plats as given in Table 1. When the averages only are con-

TABLE 1.—*The effect of lime and fertilizers on yield of hay of Korean and Kobe lespedeza grown on Cecil loam soil at Statesville, North Carolina, during 1931.*

Treatment	Hay yields in pounds per acre, 12% moisture							
	No lime				Lime			
	Replication			Average	Replication			Average
	1	2	3		1	2	3	
				Korean				
No fertilizer...	503	1,030	907	813	743	1,012	1,068	941
400 lbs. 2–10–4	719	1,886	731	1,112	620	1,517	1,103	1,080
200 lbs. 16% superphosphate	787	1,372	1,027	1,062	725	1,162	1,035	974
100 lbs. 20% manure salts	618	1,151	1,186	985	939	1,031	1,253	1,074
500 lbs. 8% basic slag	636	1,408	1,364	1,136	637	1,480	1,035	1,051
				Kobe				
No fertilizer........	2,003	1,617	2,182	1,934	2,564	2,081	2,367	2,337
400 lbs. 2–10–4....	1,673	1,542	1,889	1,701	1,941	2,755	1,806	2,167
200 lbs. 16% superphosphate	1,802	1,736	1,884	1,807	2,181	2,444	1,974	2,200
100 lbs. 20% manure salts.............	1,590	1,282	1,628	1,500	2,000	2,522	2,393	2,305
500 lbs. 8% basic slag	2,495	1,486	2,344	2,108	1,853	1,623	1,858	1,778

[4]The fertilizer analysis is given in the order of nitrogen, phosphoric acid, and potash.

sidered these data indicate that some increase in yield of the Korean variety was due to phosphate and the complete fertilizer on the unlimed area. However, inspection of the individual plat yields shows more variation between plats within a treatment than between treatments, indicating the increases are not significant. The same variation within treatments holds true on the limed area of Korean and on both areas of Kobe. However, there was no consistent variation due to treatment, as the treated plats are lower or very little higher in yield than the untreated plats. The yields of Kobe on the limed area are higher than those on the unlimed area with the exception of the yield on the basic slag treatment. As this experiment was carried on for only one year on a soil type that is quite heterogeneous, the data have not answered the question of fertilizer application in the rotation but indicate a need for additional research.

EFFECT OF FERTILIZER APPLIED TO LESPEDEZA GROWN ON AN UNPRODUCTIVE SOIL

The area selected for the experimental work was a Cecil gravelly loam soil near China Grove, North Carolina, which had been planted to Korean lespedeza during 1931 and 1932 with complete failure to obtain stands. During both seasons the lespedeza plants grew to be about 1 or 2 inches high, became yellowish in color with red leaf margins and stems, after which most of them died. In the spring of 1933 experimental plats were laid out on this field. The field was divided into five blocks with ground limestone broadcast on the first, third, and fifth blocks at the rates of 1, 2, and 3 tons per acre, respectively, the second and fourth blocks being left unlimed. The field was then divided into four areas for seeding to Korean, Kobe, common, and sericea lespedeza, each of which crossed the lime and unlimed blocks. The fertilizers were applied in triplicate strips across the limed and unlimed blocks for each of the lespedeza varieties. The fertilizer treatments were a 2–10–4, and 0–10–4, an 0–10–0, and an 0–0–4. A strip was left without fertilizer in each replicate. The fertilizer constituents were 62 pounds of ammonium sulfate, 388 pounds of 16% superphosphate, and 50 pounds of muriate of potash. The plats which did not set sufficient seed for volunteering during 1933 were reseeded in the spring of 1934. This reseeding was the only treatment during 1934.

Determinations of the pH as given in Table 2 were made with a quinhydrone electrode from samples collected in May 1933, about two months after fertilizer and lime applications. The pH values of the superphosphate plats were between 5.0 and 5.5, of the untreated plats between 5.3 and 5.7, and of the limed plats between 5.4 and 6.8. Most of the limed plats were above pH 6. There was apparently a slight increase in the soil acidity with the use of superphosphate either with or without lime. The pH of all the limed plats was higher than that of many fields which have successfully grown lespedeza in this same locality.

During both 1933 and 1934 the Korean and Kobe varieties emerged to good stands on all plats. The germination of common lespedeza

TABLE 2.—*The pH values of Cecil loam soil with different lime and phosphate treatments as determined on soil samples from plats collected in May 1933.*

Treatment	pH values	
	Korean	Kobe
No treatment	5.44	5.53
P	5.19	5.33
1 ton lime	6.40	6.02
2 tons lime	6.44	6.52
3 tons lime	6.45	6.44
P and 1 ton lime	6.20	5.98
P and 2 tons lime	6.08	6.48
P and 3 tons lime	6.46	6.25

was uniformly poor in 1933 but good in 1934. Stand estimations at the end of each season are given in Table 3. In May and June 1933 the stands of Korean were lowered to 40% on the check plats, as compared with 78 to 86% on the phosphate-treated plats, and 60 to 83% on the limed plats. Stands of Kobe were about 90 to 91% on the plats not treated with phosphate, but where phosphate was applied they were nearly perfect. Due to poor germination of the common variety the effects of the fertilizer treatments on stands, if any, were obscured.

TABLE 3.—*Stands in percentage of ground cover of lespedeza grown on Cecil gravelly loam soil with different fertilizer and lime treatments as determined in September 1933 and 1934.*

Treatment	Stand in percentage ground cover						
	Korean		Kobe		Common		Sericea, 1934
	1933	1934	1933	1934	1933	1934	
No treatment	40	5	90	24	55	0	50
K	40	8	91	31	52	0	50
P	78	33	99	54	60	0	73
PK	86	40	99	57	69	0	89
NPK	86	40	99	57	61	0	84
1 ton lime	72	57	90	80	15	80	85
2 tons lime	60	58	87	67	82	0	100
3 tons lime	83	100	98	50	75	0	100
K and 1 ton lime	75	60	90	75	13	85	90
K and 2 tons lime	63	67	90	58	52	0	100
K and 3 tons lime	80	92	97	67	65	0	100
P and 1 ton lime	90	93	100	100	32	75	100
P and 2 tons lime	88	100	98	92	87	0	100
P and 3 tons lime	99	100	100	58	68	0	100

As sericea is a perennial and full growth is not attained during the year of seeding, stand and growth determinations are given only for 1934. Stands of sericea averaged 50% on untreated plats compared with from 73 to 85% with phosphates and 85 to 100% on the limed plats. With both lime and superphosphate stands were perfect.

May 1934 was extremely dry, thus giving a test of drought resistance on a poor soil. The plants of the common variety all died regardless of treatment, the only survival being on a part of the field which had received more or less fertilizer in recent cultivation.

Kobe survived somewhat better than Korean on the untreated plats having a stand of 24% compared with 5%. This ability of Kobe to survive held true for the treated plats also, except for a part of the field which was so located as to receive more moisture due to lack of drainage.

The height of all varieties showed a significant increase to treatment with superphosphate. The Korean variety responded to lime treatment by an increase in height as compared with the unlimed plats. Lime had some effect on Kobe and common also, although the correlation coefficients were not significant.

The plants of all varieties on the plats not receiving phosphates were retarded in growth from the time of emergence until they reached a height of from 1 to 6 inches when growth stopped and many of the plants died. Fig. 1 shows the relative growth of plants of common collected at random from the different treatments on June 7, 1933. These plants were representative of the ones of the other annual varieties at the time the plants were collected. The plants of Korean without treatment stopped growth at about this stage when from 1 to 3 inches high. Kobe and common plants on untreated plats con-

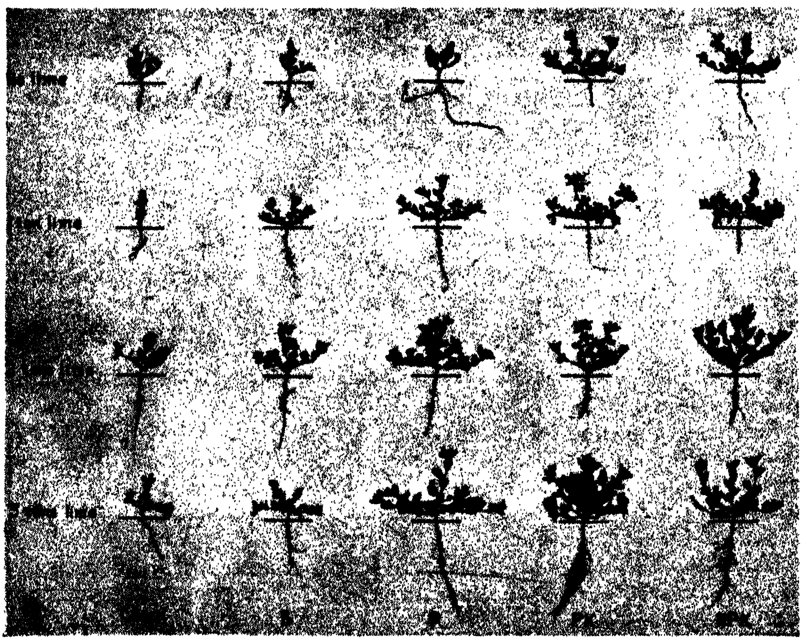

FIG. 1.—Comparative growth of common lespedeza on unproductive Cecil gravelly loam with different fertilizer and lime treatments.

tinued to grow until early in July, while those of sericea grew until August. Comparative growth on September 15, 1933, of Kobe with and without phosphate on the area receiving 2 tons lime is shown in Fig. 2.

FIG. 2. Comparative growth of Kobe lespedeza on unproductive Cecil gravelly loam with and without phosphates on the area receiving 2 tons of ground limestone. Left, phosphate, right, potash

As shown in Table 4 Korean reached a height of 1 to 3 inches, according to the year, on the untreated plats compared with 4 to 6 inches on the superphosphate plats, 4 to 13 inches on the limed plats, and 9 to 17 inches where both lime and superphosphate were used. Kobe and common were from 4 to 6 inches high on the untreated plats, 9 to 11 inches with superphosphate, 6 to 8 inches with lime, and 8 to 16 inches with both lime and superphosphate. Due to the lack of stands of the common variety during the second season, growth could not be measured.

Sericea as measured at maturity in the second season of growth was 16 inches high without phosphate, 26 inches with phosphate; 20 inches with 1 ton, 25 inches with 2 tons, and 30 inches with 3 tons of lime; and 30, 35, and 40 inches, respectively, where phosphate was added with the lime.

Samples of the Korean and Kobe varieties were cut on September 22 and analyzed for ash, calcium, phosphorus, and crude protein. The analyses are given in Table 5. The percentage of calcium was raised by both lime and superphosphate treatments. Phosphorus was higher in the plants from superphosphate plats than in those from the check and lime plats. Crude protein was slightly higher from

TABLE 4.—*Height of lespedeza grown on Cecil gravelly loam soil with different fertilizer and lime treatments as measured in September 1933 and 1934.*

Treatment	Height in inches						
	Korean		Kobe		Common		Sericea, 1934
	1933	1934	1933	1934	1933	1934	
No treatment	3	3	6	4	6	—	16
K	3	1	6	5	6	—	16
P	6	4	10	10	9	—	26
PK	7	4	10	11	10	—	26
NPK	7	4	10	11	10	—	25
1 ton lime	6	6	8	8	6	6	20
2 tons lime	4	5	6	6	6	—	25
3 tons lime	9	13	8	8	8	—	35
K and 1 ton lime	6	6	8	8	6	5	20
K and 2 tons lime	4	5	7	6	7	—	25
K and 3 tons lime	7	12	8	7	8	—	35
P and 1 ton lime	9	11	11	16	8	11	30
P and 2 tons lime	8	12	11	13	10	—	35
P and 3 tons lime	10	17	12	10	11	—	40

the limed plats and very much higher from the superphosphate plats. The protein content of Korean was much higher than Kobe which cannot be accounted for on the basis of these analyses.

TABLE 5.—*The effect of soil amendments on the ash, calcium, phosphorus, and crude protein content of lespedeza, grown on Cecil gravelly loam soil from analyses of samples collected in September 1933.*

Treatment	Percentage on dry matter basis							
	Korean				Kobe			
	Ash	CaO	P_2O_5	Crude protein	Ash	CaO	P_2O_5	Crude protein
No treatment	5.84	0.63	0.38	10.38	4.20	0.68	0.19	9.95
Superphosphate	5.30	0.82	0.47	17.19	4.50	1.09	0.28	13.75
2 tons lime	4.77	0.99	0.25	12.81	4.72	1.03	0.22	11.19
2 tons lime and superphosphate	4.10	0.86	0.45	17.00	4.86	1.09	0.31	14.00

SUMMARY

1. On a Cecil loam soil which had received a complete fertilizer during the previous season Korean lespedeza did not give a significant response to lime and fertilizer and Kobe lespedeza responded slightly to lime.

2. On a Cecil gravelly loam soil, which was too poor for normal growth without treatment, Kobe, Korean, common, and sericea lespedeza responded to phosphate and lime. The Korean variety responded more to lime than either Kobe or common.

3. In their ability to survive drought under conditions of low phosphate availability the varieties ranked with Kobe first, Korean

second, and common third. Common seemed unable to survive drought with the level of fertilizer treatment provided. *Lespedeza sericea* with its perennial root was not affected by the drought.

4. The calcium and crude protein content of Kobe and Korean lespedeza plants growing on the Cecil gravelly loam were increased by the addition of both lime and superphosphate. The phosphorus content was increased by application of superphosphate.

LITERATURE CITED

1. BLAIR, E. C. Lespedeza hay yield increased by superphosphate Phosphorus Digest, 1931 (March):8 10. 1931.
2. ESSARY, S. H. Lespedeza. Tenn. Agr. Exp. Sta. Bul. 123. 1921.
3. ETHERIDGE, E. C., HELM, C. A., and KING, B. M. Korean lespedeza in Missouri. Mo. Agr. Exp. Sta. Bul. 280 1930.
4. GISH, P. T., and HUTCHESON, T. B. Field crops on Berks shale soil respond to lime and fertilizers. Va. Agr. Exp. Sta. Bul. 292. 1923.
5. HYLAND, H. L. Comparison of legume growth in different soil types at varying acidity levels. Jour. Amer. Soc Agron , 30:111–121 1938.
6. COOPER, F. P. [Lespedeza hay] Ky. Agr. Exp Sta. Ann. Rpt., 48:57, 61. 1936.
7. PIEPER, J. J., SEARS, O. H , and BAUER, F. C Lespedeza in Illinois. Ill. Agr. Exp. Sta. Bul. 416:301 347. 1935.

COMPOSITION OF BARK AND INNER PART OF ROOTS OF THE COTTON PLANT[1]

L. E. Hessler, D. R. Ergle, N. E. Rigler, and J. E. Adams[2]

THE Division of Soil Fertility Investigations, Bureau of Plant Industry, has studied for a number of years the relation of crop residues, tillage, and crop management to production of cotton under root-rot conditions in the Blackland prairie section of Texas. Correlated laboratory studies have been made of the composition of the cotton plant as influenced by the stage of development and by fertilizer treatment.

Root-rot of cotton is caused by a root-infecting fungus, *Phymatotrichum omnivorum* (Shear) Duggar. Evidence of chemical action, by secretions of the fungus, as a factor of entry into the host plant (14)[3] centers attention on the composition of the root tissue which would serve as the nutrient medium for the growth of the fungus. In previous publications (2, 3), results were presented showing the changes in concentration of certain electrodialyzable and carbohydrate fractions of the roots and tops of the cotton plant at successive stages of growth. The results demonstrated, among other facts, that the nitrogenous fractions of the plant reflected soil conditions, fertilizer treatments, and seasonal variations better than the total nitrogen. The carbohydrates of the cotton plant were also influenced by soil fertilization, but the effects on the nitrogen and phosphorus contents were even more pronounced. The roots contained comparatively high concentrations of carbohydrates.

Additional data (4, 11) concerning the composition of whole cotton plants grown on two soils indicate that there are fairly definite changes in certain nitrogenous and carbohydrate fractions accompanying each stage of growth, namely, the seedling, early squaring, boll set, and boll-opening periods. The composition of the whole plant, however, was not as good a measure of fertilizer effects as that of the tops or roots analyzed separately (2, 3) This was particularly true for the effect of fertilizers on the concentrations of the carbohydrate fractions.

Field tests (7) have shown that high-phosphate fertilizers tend to increase root-rot on both the Wilson fine sandy loam and Houston black clay soils, while high-nitrogen fertilizers tend to decrease the amount of root-rot. The reduction was not significant on the heavier and more calcareous soil. Correlated laboratory studies (11) showed that the composition of the cotton plants was affected by the fertilizers used.

This report deals with the composition of root segregates, i. e., the bark and inner portion, stele, at different dates of sampling during the 1936 season and under varied fertilizer treatment.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 539.

PLAN OF EXPERIMENT

The roots used in this investigation were obtained from cotton plants grown in an experiment designed to study the relationship between fertilizer treatment, yield of cotton, and the occurrence of root-rot under field conditions.[4] The experiment was located on Wilson clay loam soil near Elgin, Texas. The following fertilizer treatments were replicated five times on plats which were randomized according to Fisher (5). The fertilizers used were 0-15-0[5], 3-9-3, 9-3-3, and 15-0-0; untreated check plats were included. The fertilizers were applied at the rate of 900 pounds per acre simultaneously with the planting of the experiment to cotton. Samples secured for each of the treatments consisted of a composite of an equal number of plants from each of the five replications. Morphological and other data from this experiment have been given previously in detail (7). This study covers the period from early square formation to the time bolls were opening.

The procedures for sampling of the plats and preparation of the material for analysis were the same as those given in previous publications (2, 3). For this study the bark was separated from the inner portion of the root by peeling, and each portion was treated as a separate sample. Due to the small size of the plants, samples were not collected before the appearance of squares. The severity of root-rot infestation made it inadvisable to sample after bolls began to open.

METHODS OF ANALYSIS

The analytical procedures have been given in detail in previous publications (2, 3), but are briefly repeated here.

CARBOHYDRATES

The sugars were extracted from the plant tissue with boiling 80% alcohol. The water solution, prepared from the alcoholic extract, was clarified and made to a definite volume. In determining the concentration of sugars, an aliquot of the solution was oxidized according to the Munson-Walker procedure (1), and the reduced copper determined by the Schaffer-Hartmann (12) method. The reducing power before inversion, calculated as invert sugars, was taken as a measure of the total content of reducing sugars. The reducing power, after the oxidation of the aldose sugars by the procedure of Kolthoff and Furman (8), was determined and calculated as fructose from the tables of Schoorl (8). The value for the aldose sugars was obtained by subtracting the percentage of fructose from the percentage of total reducing sugars. The total sugar content was determined after inversion with hydrochloric acid at room temperature and expressed as invert sugar. The non-reducing sugars were calculated by subtracting the percentage of reducing sugars from the percentage of total sugars.

A sample of sugar-free material was hydrolyzed with boiling hydrochloric acid for the determination of polysaccharides. The reducing power of the hydrolysate was then determined and expressed as percentage of anhydrous dextrose.

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[4]Acknowledgment is made to Messrs. H. V. Jordan, J. H. Hunter, H. A. Nelson, and P. M. Jenkins for the care of the plats and assistance in the collection of the samples.

[5]N-P_2O_5-K_2O; total equalled 15%. One-half of the nitrogen was derived from sulfate of ammonia and one-half from nitrate of soda; the P_2O_5 was from 18% superphosphate; and the potash was derived from sulfate of potash.

The total for carbohydrates was obtained by the addition of the percentage concentrations of the individual carbohydrate fractions.

All analytical results were expressed as percentage concentrations in fresh plant material.

ELECTRODIALYZABLE COMPONENTS

The dialysates obtained by the precedure previously described (2, 11) were adjusted to definite volumes, usually 1,000 cc, and suitable aliquots removed for analysis.

Equal aliquots of cathode and anode solutions, usually 50 cc, were combined and hydrolyzed to obtain the "ammonium plus amide" nitrogen. The ammonia was removed by aeration, and determined by titration.

Portions of anolyte and catholyte (50 cc each) were combined, and concentrated to less than 10 cc for the amino-nitrogen determination. The solution was then diluted to exactly 10 cc, and 2 cc aliquots were transferred to a Van Slyke micro-apparatus for analysis. The results were expressed as percentages of alpha-amino nitrogen.

Phosphotungstic acid was used to precipitate the basic nitrogen from a 200-cc aliquot of cathode solution after concentrating to about 50 cc. The nitrogen in the precipitate was determined by a Kjeldahl analysis.

The nitrogen in 50 cc of the cathode dialysate was determined by the Kjeldahl method to obtain the total cathode nitrogen.

The nitrogen in 50- to 100-cc aliquots of anode dialysate was determined by the Kjeldahl method modified to include nitrates. This is called total anode nitrogen.

Interfering substances were removed from an appropriate aliquot of the anolyte (5 to 20 cc) by means of silver sulfate and calcium oxide, and the content of nitrate nitrogen determined colorimetrically.

A 10-cc aliquot of the anode portion was diluted (usually to 250 cc) and 50 cc of this solution analyzed colorimetrically for phosphates according to the method of Truog and Meyer (13).

The residue from the central chamber was dried to constant weight at 100° C and analyzed for nitrogen and phosphorus. The nitrogen was determined by the Kjeldahl method. A 1-gram sample of the residue was digested according to the method of Gerritz (6), and the phosphorus content determined colorimetrically.

Analyses of the residue after dialysis are expressed as percentage of dialyzed material dried at 65° to 70° C.

RESULTS OF THE EXPERIMENT

CARBOHYDRATES

The carbohydrate fractions of the bark and inner portions of the roots of the cotton plants at different stages of growth from fertilized and unfertilized plats are given in Table 1. The concentrations of total reducing sugars, aldose sugars, and ketose sugars in the roots of plants from unfertilized plats are shown graphically in Fig. 1, B and D, and total sugars, polysaccharides, and total carbohydrates in Fig. 1, A and C. The seasonal trends of the data for fertilized and unfertilized plants are essentially the same so the discussion is confined principally to data from unfertilized plants.

The total amount of simple sugars is considerably greater in the bark than in the inner portion of the root. The range in concentration

is from about 0.5 to 1.1% in the bark and from 0 2 to 0 4% in the stele. The average concentration of aldose sugar in the bark is 0 40% and of ketose 0 45% Although the difference in the average concentrations of aldose and ketose sugars is not particularly outstanding, that of ketose sugars fluctuates markedly during the season, while the change in the concentration of aldose sugars is gradual In general, the ketose content of the bark is high when that of aldose is low,

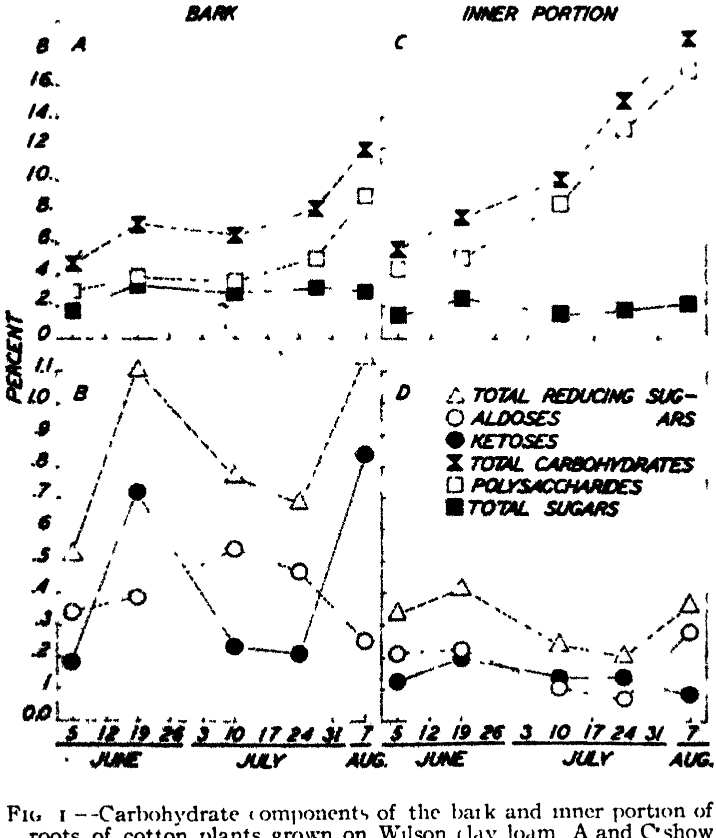

FIG. 1.—Carbohydrate components of the bark and inner portion of roots of cotton plants grown on Wilson clay loam A and C show total carbohydrates, polysaccharides and total sugars B and D, total reducing sugars, aldoses, and ketoses.

and vice versa. The average aldose-sugar content of the inner portion is greater than that of the ketose; the concentrations are 0.18 and 0.13%, respectively.

The concentrations of polysaccharides and total sugars in the bark do not vary greatly until after July 10 and then an increase in the polysaccharide fraction is evident. The stele shows a considerably larger content of polysaccharides than of sugars, even at the early dates of sampling. The polysaccharide content increases rapidly after June 19. The amount of total carbohydrates in the inner portion

TABLE 1.—*Some carbohydrate fractions of the bark and inner portion of the roots of cotton plants at different stages of growth produced on Wilson clay loam soil with varying fertilizer treatment.**

Date of sampling, 1936	Treatment	Sugars: Aldose %	Sugars: Ketose %	Sugars: Total reducing %	Sugars: Non-reducing %	Sugars: Total %	Poly-saccharides %	Total carbo-hydrates %	Weight of root part from 1 plant, grams
				Bark of Root					
June 5	0–15–0	0.47	0.15	0.62	1.29	1.91	2.80	4.71	—
June 19		0.66	0.82	1.48	2.17	3.65	3.19	6.84	2.21
July 10		0.74	0.40	1.14	1.42	2.56	4.14	6.70	5.78
July 24		0.56	0.20	0.76	2.11	2.87	4.66	7.53	8.58
Aug. 7		0.45	0.65	1.10	1.84	2.94	8.66	11.60	10.76
Average		0.58	0.44	1.02	1.77	2.79	4.69	7.48	6.83
				Inner Portion of Root					
June 5	—	0.14	0.16	0.30	1.09	1.39	4.52	5.91	—
June 19		0.25	0.19	0.44	1.94	2.38	6.11	8.49	2.13
July 10		0.12	0.14	0.26	1.33	1.59	9.48	11.07	4.82
July 24		0.14	0.13	0.27	1.50	1.77	12.27	14.04	7.14
Aug. 7		0.27	0.16	0.43	1.62	2.05	16.53	18.58	10.76
Average		0.18	0.16	0.34	1.50	1.84	9.78	11.62	6.21
				Bark of Root					
June 5	3–9–3	0.78	0.44	1.22	0.54	1.76	2.75	4.51	—
June 19		0.54	0.75	1.29	2.13	3.42	3.64	7.06	3.16
July 10		0.57	0.27	0.84	1.75	2.59	3.53	6.12	7.78
July 24		0.61	0.23	0.84	2.05	2.89	4.25	7.14	11.07
Aug. 7		0.15	1.23	1.38	1.83	3.21	7.96	11.17	10.80
Average		0.53	0.58	1.11	1.66	2.77	4.43	7.20	8.20

				Inner Portion of Root					
June 5	—	0.15	0.17	0.32	0.97	1.29	4.41	5.70	—
June 19		0.30	0.13	0.43	1.62	2.05	6.48	8.53	3.28
July 10		0.12	0.15	0.27	1.14	1.41	9.57	10.98	6.40
July 24		0.11	0.18	0.29	1.27	1.56	12.22	13.78	10.39
Aug. 7		0.17	0.15	0.32	1.56	1.88	14.88	16.76	11.45
Average		0.17	0.16	0.33	1.31	1.64	9.51	11.15	7.88
				Bark of Root					
June 5	9–3–3	0.62	0.27	0.89	0.85	1.74	2.82	4.56	—
June 19		0.61	0.73	1.34	2.27	3.61	3.66	7.27	2.56
July 10		0.51	0.34	0.85	1.73	2.58	3.50	6.08	6.82
July 24		0.53	0.22	0.75	2.27	3.02	4.44	7.46	8.82
Aug. 7		0.12	1.00	1.12	2.26	3.38	7.46	10.84	15.02
Average		0.48	0.51	0.99	1.88	2.87	4.38	7.24	8.31
				Inner Portion of Root					
June 5	—	0.19	0.15	0.34	0.93	1.27	4.55	5.82	—
June 19		0.26	0.19	0.45	1.79	2.24	5.57	7.81	2.79
July 10		0.12	0.12	0.24	1.10	1.34	7.76	9.10	6.20
July 24		0.09	0.13	0.22	1.38	1.60	11.86	13.46	7.30
Aug. 7		0.24	0.14	0.38	1.65	2.03	14.91	16.94	16.30
Average		0.18	0.15	0.33	1.37	1.70	8.93	10.63	8.15
				Bark of Root					
June 5	15–0–0	0.54	0.30	0.84	0.93	1.77	3.00	4.77	—
June 19		0.52	0.63	1.15	2.26	3.41	3.55	6.96	1.29
July 10		0.75	0.27	1.02	1.60	2.62	3.83	6.45	4.80
July 24		0.48	0.17	0.65	2.44	3.09	4.85	7.94	7.50
Aug. 7		0.26	0.86	1.12	2.80	3.92	7.62	11.54	10.60
Average		0.51	0.45	0.96	2.01	2.96	4.57	7.53	6.05

*All data expressed on green weight basis.

TABLE 1.—*Concluded.*

Date of sampling, 1936	Treatment	Sugars: Aldose %	Sugars: Ketose %	Sugars: Total reducing %	Sugars: Non-reducing %	Sugars: Total %	Poly-saccharides %	Total carbo-hydrates %	Weight of root part from 1 plant, grams
				Inner Portion of Root					
June 5	——	0.16	0.16	0.32	1.14	1.46	4.40	5.86	——
June 19		0.19	0.15	0.34	2.04	2.38	4.93	7.31	1.29
July 10		0.13	0.10	0.23	1.09	1.32	6.86	8.18	4.34
July 24		0.09	0.09	0.18	1.34	1.52	10.78	12.30	5.63
Aug. 7		0.16	0.12	0.28	1.92	2.20	16.82	19.02	10.67
Average		0.15	0.12	0.27	1.51	1.78	8.76	10.53	5.48
				Bark of Root					
June 5	No fertilizer	0.34	0.18	0.52	1.22	1.74	2.89	4.63	——
June 19		0.38	0.72	1.10	2.25	3.35	3.72	7.07	1.29
July 10		0.54	0.23	0.77	2.00	2.77	3.62	6.39	4.88
July 24		0.47	0.21	0.68	2.38	3.06	4.99	8.05	6.58
Aug. 7		0.25	0.89	1.14	1.71	2.85	8.99	11.84	9.86
Average		0.40	0.45	0.84	1.91	2.75	4.84	7.60	5.65
				Inner Portion of Root					
June 5	——	0.21	0.12	0.33	1.04	1.37	4.30	5.67	——
June 19		0.22	0.19	0.41	2.09	2.50	5.08	7.58	1.24
July 10		0.10	0.13	0.23	1.27	1.50	8.46	9.96	4.12
July 24		0.07	0.13	0.20	1.62	1.82	13.21	15.03	4.80
Aug. 7		0.28	0.08	0.36	1.69	2.05	16.83	18.88	9.18
Average		0.18	0.13	0.31	1.54	1.85	9.58	11.42	4.84

*All data expressed on green weight basis.

of the root is influenced more by the polysaccharide content than by the sugar content, and, except for the early period, is from three to eight times greater than that of the total sugars. The total sugars in the bark during the first half of the season affect markedly the level of the total carbohydrates, but as the season advances the higher concentration of polysaccharides dominates.

There is evidence from the relative amounts of the different forms of carbohydrates in the two root parts that a concentration and activity gradient exist between the bark and stele. Reducing and non-reducing sugars are present in the bark in larger amounts than in the stele, while the converse is true for the more complex carbohydrates.

ELECTRODIALYSIS DATA

The data for the nitrogen fractions of the bark and inner portions of the roots of cotton plants for different growth periods on fertilized and unfertilized soil are given in Table 2. In Fig. 2, A and D, are

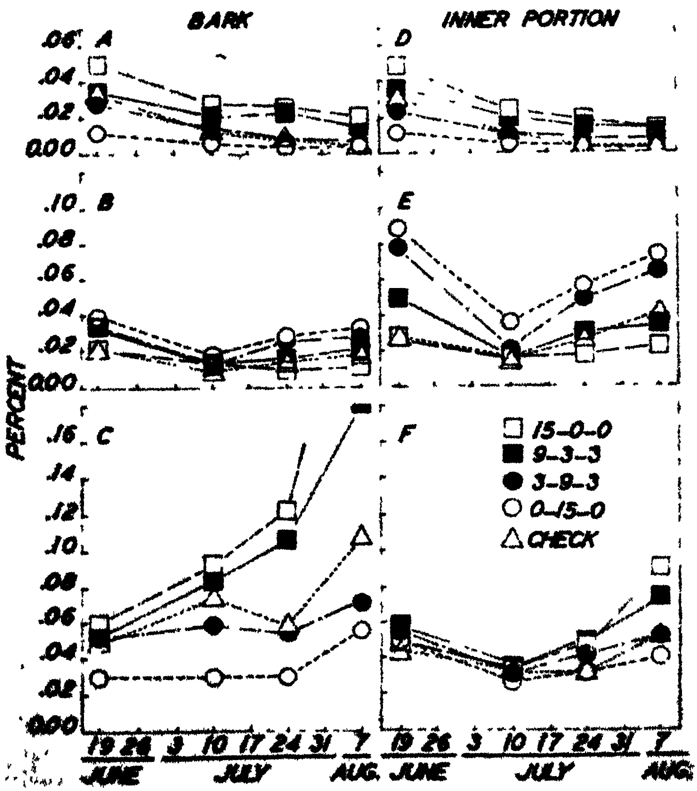

FIG. 2.—Electrodialyzable nitrogenous components of roots of cotton plants produced on Wilson clay loam. A and D show total anode nitrogen, B and E, P_2O_5; and C and F, total cathode nitrogen.

TABLE 2.—*Some electrodialyzable components of the bark and inner portion of the roots of the cotton plant at different stages of growth produced on Wilson clay loam with various fertilizer treatments.**

Date of sampling, 1936	Treatment	Weight per plant, grams	% of total root weight	Amide + ammonium N, %	Amino N, %	Basic N, %	Cathode N, %	Anode N, %	Total anode + cathode N, %	N in residue %	Inorganic phosphate, P_2O_5 %	P_2O_5 in residue %	Residue after dialysis %
						Bark of Root							
June 19....	0–15–0	2.21	50.8	0.011	0.011	0.009	0.030	0.012	0.042	0.155	0.039	0.030	16.8
July 10....		5.78	53.4	0.006	0.009	0.008	0.030	0.006	0.036	0.127	0.018	0.029	17.0
July 24....		8.58	54.6	0.008	0.008	0.006	0.030	0.003	0.033	0.139	0.028	0.033	18.5
Aug. 7....		10.76	50.0	0.018	0.009	0.010	0.056	0.004	0.060	0.151	0.027	0.042	24.8
Average		6.83	52.2	0.011	0.009	0.008	0.037	0.006	0.043	0.143	0.028	0.034	19.3
						Inner Portion of Root							
June 19....	——	2.13	49.2	0.016	0.015	0.018	0.048	0.012	0.060	0.128	0.089	0.029	23.7
July 10....		4.82	46.6	0.005	0.007	0.009	0.026	0.005	0.031	0.117	0.035	0.034	32.3
July 24....		7.14	45.4	0.008	0.013	0.007	0.031	0.004	0.035	0.124	0.056	0.038	38.6
Aug. 7....		10.76	50.0	0.009	0.014	0.012	0.040	0.004	0.044	0.129	0.073	0.049	47.1
Average		6.21	47.8	0.010	0.012	0.012	0.036	0.006	0.043	0.125	0.063	0.038	35.4
						Bark of Root							
June 19....	3–9–3	3.16	49.1	0.019	0.016	0.015	0.052	0.028	0.080	0.162	0.034	0.035	16.0
July 10....		7.78	54.9	0.017	0.021	0.019	0.059	0.014	0.073	0.130	0.013	0.029	16.5
July 24....		11.07	51.5	0.018	0.018	0.012	0.054	0.007	0.061	0.146	0.026	0.033	17.9
Aug. 7....		10.80	48.1	0.022	0.025	0.017	0.071	0.006	0.077	0.185	0.032	0.046	24.2
Average		8.20	50.9	0.019	0.020	0.016	0.059	0.014	0.073	0.156	0.026	0.036	18.7
						Inner Portion of Root							
June 19....	——	3.28	50.9	0.015	0.016	0.015	0.054	0.023	0.077	0.136	0.078	0.030	22.9
July 10....		6.40	45.1	0.006	0.004	0.009	0.031	0.010	0.041	0.125	0.020	0.025	31.4
July 24....		10.39	48.5	0.009	0.009	0.013	0.041	0.007	0.048	0.139	0.049	0.032	37.5
Aug. 7....		11.45	51.9	0.010	0.020	0.018	0.052	0.006	0.058	0.100	0.064	0.047	43.6
Average		7.88	49.1	0.010	0.012	0.014	0.045	0.012	0.056	0.125	0.053	0.034	33.9

						Bark of Root							
June 19....	9–3–3	2.56	47.8	0.016	0.012	0.015	0.052	0.034	0.086	0.169	0.034	0.026	16.0
July 10....		6.82	52.4	0.027	0.010	0.022	0.084	0.021	0.105	0.143	0.012	0.029	16.3
July 24....		8.82	54.7	0.036	0.047	0.016	0.106	0.023	0.129	0.154	0.016	0.024	17.4
Aug. 7.....		15.02	48.0	0.067	0.077	0.032	0.180	0.015	0.195	0.178	0.019	0.032	22.9
Average		8.31	50.7	0.037	0.037	0.021	0.106	0.023	0.129	0.161	0.020	0.028	18.2
						Inner Portion of Root							
June 19....	——	2.79	52.2	0.013	0.012	0.015	0.057	0.036	0.093	0.142	0.049	0.034	22.4
July 10....		6.20	47.6	0.007	0.003	0.010	0.034	0.020	0.054	0.117	0.016	0.023	29.1
July 24....		7.30	45.3	0.011	0.020	0.016	0.049	0.014	0.063	0.148	0.030	0.039	38.5
Aug. 7.....		16.30	52.0	0.015	0.026	0.027	0.073	0.009	0.082	0.113	0.034	0.042	44.4
Average		8.15	49.3	0.012	0.015	0.017	0.053	0.020	0.073	0.130	0.032	0.035	33.6
						Bark of Root							
June 19....	15–0–0	1.29	50.0	0.030	0.009	0.021	0.060	0.049	0.109	0.153	0.021	0.015	14.6
July 10....		4.80	52.6	0.033	0.024	0.020	0.092	0.027	0.119	0.146	0.010	0.024	16.4
July 24....		7.50	57.1	0.046	0.052	0.017	0.122	0.026	0.148	0.133	0.010	0.030	15.3
Aug. 7.....		10.60	49.9	0.106	0.102	0.052	0.277	0.021	0.298	0.167	0.011	0.033	23.6
Average		6.05	52.4	0.054	0.047	0.028	0.138	0.031	0.169	0.150	0.013	0.026	17.5
						Inner Portion of Root							
June 19....	——	1.29	50.0	0.018	0.020	0.017	0.048	0.048	0.096	0.137	0.027	0.029	19.8
July 10....		4.34	47.4	0.007	0.013	0.009	0.033	0.023	0.056	0.112	0.016	0.019	27.2
July 24....		5.63	42.9	0.011	0.018	0.011	0.047	0.018	0.065	0.138	0.017	0.030	34.9
Aug. 7.....		10.67	50.1	0.024	0.030	0.036	0.090	0.010	0.100	0.156	0.022	0.036	46.3
Average		5.48	47.6	0.015	0.020	0.018	0.055	0.025	0.079	0.136	0.021	0.029	32.1
						Bark of Root							
June 19....	No fertilizer	1.29	51.0	0.017	0.007	0.014	0.049	0.033	0.082	0.165	0.021	0.033	16.0
July 10....		4.88	54.2	0.022	0.029	0.019	0.073	0.013	0.086	0.136	0.009	0.026	17.1
July 24....		6.58	57.9	0.022	0.022	0.010	0.058	0.008	0.066	0.137	0.013	0.025	17.2
Aug. 7.....		9.86	51.8	0.041	0.025	0.016	0.106	0.005	0.111	0.162	0.018	0.036	24.0
Average		5.65	53.7	0.026	0.021	0.015	0.072	0.015	0.086	0.150	0.015	0.030	18.6
						Inner Portion of Root							
June 19....	——	1.24	49.0	0.015	0.016	0.013	0.045	0.030	0.075	0.131	0.027	0.027	20.8
July 10....		4.12	45.8	0.008	0.013	0.009	0.032	0.010	0.042	0.116	0.013	0.022	30.2
July 24....		4.80	42.1	0.012	0.002	0.008	0.031	0.004	0.035	0.121	0.026	0.027	37.9
Aug. 7.....		9.18	48.2	0.011	0.020	0.018	0.052	0.004	0.056	0.159	0.040	0.038	47.3
Average		4.84	46.3	0.012	0.013	0.012	0.040	0.012	0.052	0.132	0.027	0.029	34.1

*Data expressed on green weight basis.

shown graphically the concentrations of anode nitrogen for the bark and inner portion. The general trend of anode nitrogen is downward as the season advances. The concentration in the two root parts is about the same. The high-nitrogen fertilizers have caused an increase in concentration and high-phosphate fertilizers show some tendency to suppress the anode nitrogen as compared with the unfertilized plat.

Fig. 2, C and F, shows the effect of fertilizer on the total cathode nitrogen level of the two root parts. The bark is definitely richer in this nitrogenous fraction than the inner portion of the root and there is an appreciable effect from fertilizers. The trend is upward, in the bark, as the season advances, and the effect of the high-nitrogen fertilizers is pronounced. There is a definite suppression of the cathode nitrogen in the bark by high-phosphate fertilizers, the effect being greater for the 0-15-0 than for the 3-9-3 mixture. The effect of high-nitrogen fertilizers on cathode nitrogen is noticeable in the inner portion of the root, but this is not as marked as in the bark. From the data in Table 2 it is apparent that the cathode fraction is high in amino and basic nitrogen, the relative amounts being in the order given. A rapid increase in the amino nitrogen due to nitrogen fertilizers starts on July 10, while that for basic nitrogen starts 14 days later. An increase in "ammonium plus amide" nitrogen also contributes to this late-season rise. The rise at the last date of sampling for the 0-15-0 treatment is due principally to the "ammonium plus amide" fraction, as the basic-nitrogen fraction shows only a slight increase at that time.

In Fig. 2, B and E, are given the concentrations of dialyzable P_2O_5 in the bark and the inner portion of the root. The effects of the various fertilizers on dialyzable P_2O_5 are more apparent for the inner part of the root than the bark. The 0-15-0 and 3-9-3 fertilizers have definitely increased the concentration over that of the unfertilized samples. The 9-3-3 fertilizer exerted a positive effect only in the young cotton. The lower concentration due to the 15-0-0 ratio at the last two dates of sampling may be due to the prolonged vegetative condition of the plant induced by the added nitrogen.

As seen in Table 2, the average amounts of P_2O_5 remaining in the residues after dialysis do not vary greatly for the two root parts, except in the 9-3-3 sample. In this case the concentration in the stele is considerably greater than that of the bark. Nitrogen alone, 15-0-0, reduced the concentration of residual P_2O_5 in the bark early in the season; but had little effect on the inner portion of the root.

The weights of the bark and stele for the various plants, as given in Table 2, are of interest. The 9-3-3 fertilizer produced a larger average weight of bark and woody material per plant, followed in order by the 3-9-3, 0-15-0, 15-0-0, and check samples.

DISCUSSION

From a detailed study of the transport of carbohydrates in the cotton plant, Mason and Maskell (9, 10) have shown that translocation of sugars takes place through the bark. The data given in this paper, showing much higher concentrations and greater fluctuations of sugars in the bark than in the inner portion at four dates of

sampling seem to support their conclusions. While the entire root of the cotton plant undoubtedly functions as a storage organ, these differences in concentration of both labile and non-labile carbohydrates suggest that the bark and stele differ somewhat in their individual function. It would seem that the stele acts principally as a storage organ while the bark is primarily concerned with transport during the fruiting period and storage becomes a secondary function.

In addition to being richer in soluble carbohydrates the root bark contains more dialyzable nitrogen than the stele. A study of the data in Tables 1 and 2 and Fig. 2 indicates that the concentrations of the nitrogenous constituents have been affected by fertilizer treatment to a greater extent than have the carbohydrate constituents.

The greater concentrations of organic and inorganic phosphorus in the inner portion of the root than in the bark seem significant as the inner portion is also richer in the more complex carbohydrates. Reference to Table 1 shows that the inner portions of roots fertilized with the high-phosphate fertilizers 0-15-0 and 3-9-3 contained higher concentrations of polysaccharides than did those grown with fertilizers high in nitrogen (15 0 0 and 9-3-3). This indicates a correlation of phosphorus content with the formation of the storage carbohydrates. The high level of polysaccharides for the unfertilized check may be due to a lack of nitrogen for protein formation, and, consequently, a lower utilization of carbohydrates.

SUMMARY

The bark was separated from the stele of roots of cotton plants grown on Wilson clay loam soil under various fertilizer treatments. These two root parts were analyzed for some of the carbohydrate fractions, and for the fractions separable by electrodialysis. Under the conditions of the experiment, covering the period from early square formation to early opening of bolls, it was found that the bark is particularly rich in the labile carbohydrate and dialyzable nitrogenous constituents. The inner portion of the root contained more polysaccharides and dialyzable and non-dialyzable phosphates. The latter constituents increased when phosphates were added to the soil. All nitrogen fractions in the root parts are influenced to some degree by the composition of the fertilizer used. The cathode-nitrogen constituents in the bark are most markedly affected.

The ketose sugars appear to play an important part in the physiology of the cotton plant.

The data secured in these experiments show that an analysis of cotton root parts is a promising line of investigation in studying the effect of fertilizers on the composition of cotton plants at various stages of growth.

LITERATURE CITED

1. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Methods of Analysis. Washington, D. C. Ed. 3. 1930.
2. COLLINS, E. R., and RIGLER, N. E. Effect of fertilizers on some nitrogenous and other constituents of the cotton plant as separated by electrodialysis at different stages of growth. Soil Science, 44:217–229. 1937.

3. ERGLE, D. R. Carbohydrate content of cotton plants at different growth periods and the influence of fertilizers. Jour. Amer. Soc. Agron., 28:775–786. 1936.
4. ———, HESSLER, L. E., and ADAMS, J. E. Carbohydrates of the cotton plant under different seasonal conditions and fertilizer treatment. Jour. Amer. Soc. Agron., 30:951–959. 1938.
5. FISHER, R. A. Statistical Methods for Research Workers. Edinburg: Oliver and Boyd. Ed. 4. 1932.
6. GERRITZ, H. W. Digesting biological materials for calcium and phosphorus analysis. Ind. Eng. Chem., Anal. Ed., 7:167–168. 1935.
7. JORDAN, H. V., HUNTER, J. H., and ADAMS, J. E. The relation of fertilizers to the cotton plant produced in the Blackland prairie section of Texas. Jour. Amer. Soc. Agron., 30:254–262. 1938.
8. KOLTHOFF, J. M., and FURMAN, N. H. Volumetric Analysis, Vol. 2. New York: John Wiley and Sons, Inc. 1929.
9. MASON, T. G., and MASKELL, E. J. Studies on the transport of carbohydrates in the cotton plant. I. A study of diurnal variation in the carbohydrates of leaf, bark, and wood, and of the effects of ringing. Ann. Bot., 42:190–253. 1928.
10. ———, ———. Studies on the transport of carbohydrates in the cotton plant. II. The factors determining the rate and the direction of movement of sugars. Ann. Bot., 42:571 636. 1928.
11. RIGLER, N. E., ERGLE, D. R., and ADAMS, J. E. Some nitrogenous and other electrodialyzable constituents of the cotton plant at different stages of growth under differential fertilizer treatment. Soil Sci. Soc. Amer. Proc., 2:367–374. 1937.
12. SCHAFFER, P. A., and HARTMANN, A. F. The iodometric determination of copper and its use in sugar analysis. II. Methods for the determination of reducing sugars in blood, urine, milk and other solutions. Jour. Biol. Chem., 45:365-390. 1921.
13. TRUOG, E., and MEYER, A. H. Improvements in the Deniges colorimetric method for phosphorus and arsenic. Ind. Eng. Chem., Anal. Ed., 1:136–139. 1929.
14. WATKINS, G. M. Cytology of phymatotrichum root rot of cotton seedlings grown in pure culture. Amer. Jour. Bot., 25:118–124. 1938.

NATURAL SUCCESSION OF VEGETATION ON ABANDONED FARM LANDS IN THE ROSEBUD SOIL AREA OF WESTERN NEBRASKA[1]

B. I. JUDD AND M. L. JACKSON[2]

ONE of the most interesting and valuable features of natural grassland vegetation is its ability to re-establish itself after it has been disturbed by close grazing or cultivation. The ecologist has made this process the object of careful botanical investigation (17, 18, 23),[3] and the agronomist has paid particular attention to its relation to grazing management. Abandonment of cultivated land on a large scale in recent years in many Great Plains areas has made the natural revegetation process important in erosion control and restoration of the land to hay production and grazing use.

The purpose of this paper is to present further information on the process of natural succession of vegetation on previously cultivated, abandoned farm lands in a semi-arid region. Comparisons are made to conditions in grazed and undisturbed virgin grasslands. A limited consideration is given to seed viability of some native plants. The data show, in general, the time required to secure a grass vegetative cover of agronomic value, and in addition have an ecologic application to the questions of what is the true climax vegetation of the region and how to judge the age of a succession by the species present. The study has a general application to the Brown and Dark Brown Soil Zones (11, 12) from Texas through the Dakotas where abandonment has followed over extension of cultivated crop acreage, although the species in the succession vary somewhat over this large area.

LOCATION OF THE AREA AND ORIENTATION OF THE STUDY

All observations were made in Kimball County, Nebraska, the geographic location of which is shown in Fig. 1. The elevation is about 5,000 feet; the mean annual rainfall is 16 inches; and the mean annual temperature is 47° F. The U. S. Soil Survey Bulletin (14) describes the physiography, climate, and soils of the county. Jackson, Hayes, and Weldon (7) have given detailed descriptions of chemical and morphological characteristics of the Rosebud and associated soil series of the study area. Judd and Weldon (9) have discussed the changes occurring

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[3]Figures in parenthesis refer to "Literature Cited", p. 556.

in the rate of infiltration of water and in the content of organic matter, nitrogen, and root material in the soil during the process of natural revegetation.

The natural vegetation of the region, according to Weaver and Clements (23) was originally mixed grasses, including such mid-grasses as *Stipa* and *Agropyron*. These species have been reduced in abundance and stature by grazing and periodic drouth, and in some areas have been practically eliminated. The resulting vegetation is a short-grass disturbance climax of buffalo (*Buchloe dactyloides*)[4] and blue grama (*Bouteloua gracilis*) grasses with a sedge (*Carex filifolia*) as an abundant associate. This association in its normal development produces a dense sod, is low growing and carpet-like, and has few forbs except in the more moist years. Shantz has described in detail the individual associations (19, 20).

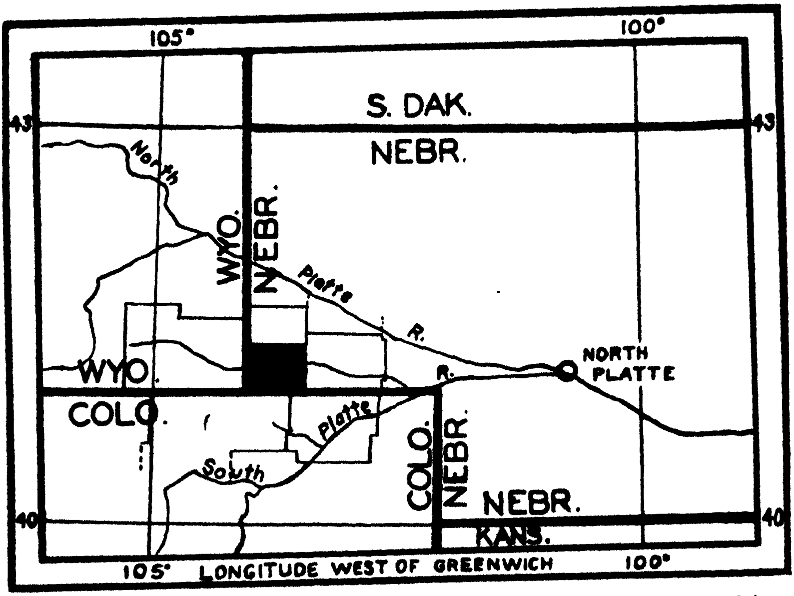

FIG. 1.—Index map showing geographic location of Kimball County, Nebr.

GENERAL PROCEDURE AND METHODS FOR MEASURING ABUNDANCE OF VEGETATION

Period of abandonment.—Abandoned fields were first located in various parts of the county by direct observation and sketched on a base map. Before detailed study of the vegetation was begun, cropping histories on abandoned tracts were secured from the leases and other records of realtors, and in a few instances from farmers and other persons of long residence in the vicinity. The historical data secured for each field studied in detail included the date of abandonment and, in most cases, the date of breaking and the crop sequence for the few years just preceding abandonment. As would be supposed, cropping history could be secured on but a fraction of the total number of abandoned fields. Quadrat studies were carried out only on the fields for which history could be secured.

[4]Acknowledgments for the various species names used in this paper are made in Table 1. All nomenclature is according to the usage of Britton and Brown (2), Hitchcock (6), and (or) Rydberg (16).

Abundance of species.—By *abundance* is meant the proportion of each species present expressed as percentage of total number of stems. The term *frequency* is used to designate the proportion of quadrats in which one or more stems of a given species occurs and is expressed as percentage of total number of quadrats. *Density* of vegetation, as herein used, refers to the average number of stems per quadrat.

The choice of size and number of quadrats was guided chiefly by the experience of other investigators (15, 3, 4, 5, 10, 13), who reported that in general 25 to 50 quadrats are sufficient and that quadrats 0.1 square meter in area give essentially the same results as larger ones. Preliminary trials in the field led to the conclusion that 20 to 40 quadrats 30 cm square were satisfactory from a statistical viewpoint. The data reported in this paper are therefore based on 20 to 40 quadrats 0.09 square meter in area (30 cm square), taken at regular intervals of 2 or 4 rods along a line perpendicular to the principal alternes[5] of vegetation. The number of stems of each species was recorded for each quadrat so that density, frequency (listed species), and abundance interpretations are possible for each species.

In the calculations of these constants, the following procedure was used: (a) The average total number of stems per 0.09 sq. m. quadrat was calculated for each field studied. This is the density of vegetation for a given field. (b) The average number of stems of each species per quadrat was computed for each field. This is density of each species. (c) In case several fields of the same period of abandonment were studied, the density of vegetation and the density of each species were computed for the series of fields from the individual field averages or densities in (a) and (b). (d) The abundance of each species (percentage of the total number of stems) was computed from the average densities in (c). Abundance computed in this manner is, of course, not the same as average abundance computed from abundance of species on each field. Abundance computed as outlined is thought to be more representative of actual hay and pasture values of the fields. (e) The frequency for each species for each field was computed and the average frequency for fields of the same period of abandonment was taken.

Procedure for determining viability of seeds is given with the discussion of viability data.

FACTORS INFLUENCING SUCCESSION OF VEGETATION

Plant succession consists of a series of temporary plant communities, one replacing another as rapidly as a given community alters the environment so as to make it more favorable for the following community than for itself, until climax vegetation finally results. The principal factors controlling the succession are the climate, soil, and past and present land-use.

Precipitation records for the region of study are summarized in Fig. 2. On the average, two-thirds of the mean annual precipitation comes during the five months, April to August. Broad variation is indicated by the data for the wettest and driest years ever recorded. The 48-year annual mean is 16.1 inches. For the first 24 years, the mean is 15.6 inches, and for the last 24 years, 16.6 inches. For the decade 1921–1930, the mean is unusually high, 17.9 inches. During

[5]Alternes of vegetation are local zones or bands of vegetation conditioned by drainage, relief, moisture supply, and other environmental factors which vary regularly and thus give successive and related zones of vegetation.

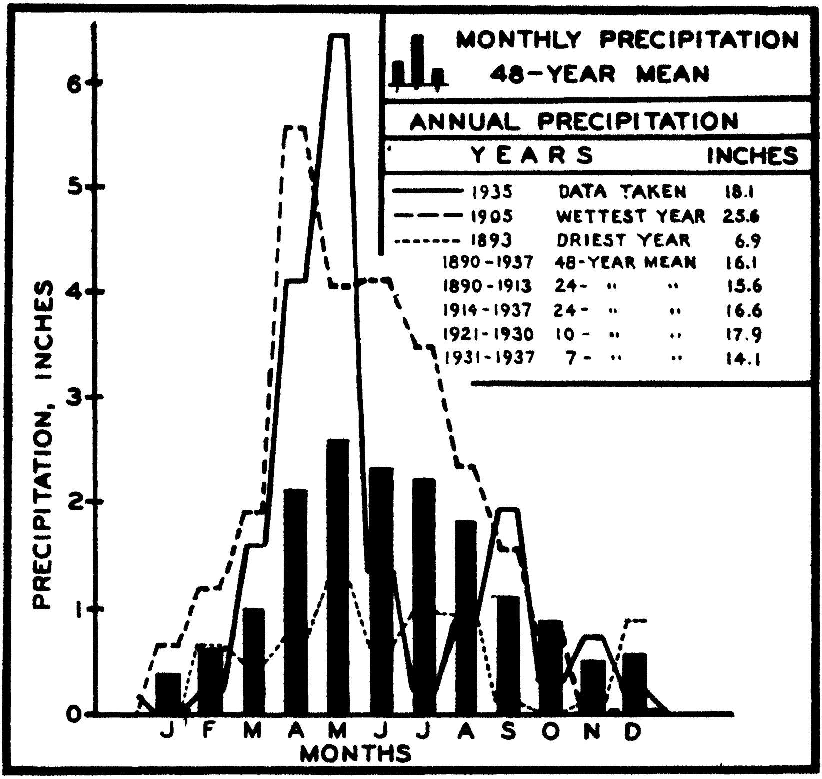

FIG. 2.—Seasonal distribution of precipitation at Kimball, Nebr., and comparison of annual precipitation of selected periods to the mean annual.

this period considerable grassland was broken for wheat growing, and it is not surprising that abandonment has followed during the last seven years with a mean precipitation of only 14.1 inches. The year 1935, during which detailed field observations were made, represents a distinct break in a series of drouth years. A wet spring gave rise to a more dense population for study and an accentuation of differences in the fields of various periods of abandonment. Thus the time of study was opportune for measurements, yet none the less representative of composition, for wide variations from drouth to relatively wet seasons are normal for the region.

SOIL FACTORS

In the region under study any soil character which increases or decreases the amount of water available for plant growth produces a corresponding alteration in vegetation. Jackson, Hayes, and Weldon (7) pointed out some of the relationships between the profile characteristics of the soils of the area, the moisture supply, and the development of vegetation. They show, for example, that stony soils

encourage deeper penetration of water into the soil and consequently support a tall bunch-grass type of native vegetation. Weaver (22) has discussed grass-root relations in the normal soils.

Local environmental associations are indicated in Fig. 3 by letters A to E. The marsh types (A) are nearly static and were almost entirely excluded from the field observations. The place of *Agropyron smithii* (western wheat grass) is broad in the succession studies. It predominates in the upland drain bottoms and at the margins of ponds (B) and completely occupies some of the smaller depressions. It appears as a stage in plant succession as will be pointed out later and persists permanently in the uplands on the heavy soils. A belt of annuals (C) persists just outside of the wheat grass alterne around the ponds. *Chenopodium album* (lamb's quarters) and *Sisymbrium*

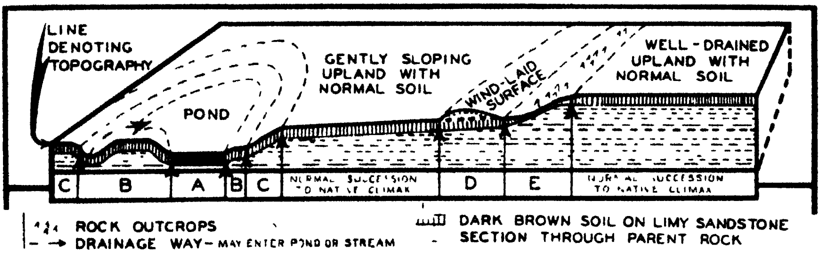

FIG. 3.—The ecologic relationships of vegetation to topography and soil development, Kimball County, Nebr., 1935–37. A, hydrosere, marsh types, *Jungus* sp.; B, pond margins and drain bottoms, *Agropyron smithii* predominates; C, alternes, mostly forbs, influenced by pond; D, retardation by wind deposition, *Chenopodium album*, *Sisymbrium altissimum*, *Helianthus annuus*, *H. petiolaris*; and E, native relicts condition rapid succession to sub-climax and post-climax.

altissimum (tumbling mustard) are the chief species. Periodic inundation combined with wind deposition favors the annuals and disfavors further progress in the succession. Beyond this alterne are encountered the areas of true succession, located on the gently sloping uplands with normal soils. It is here that the quadrat data were taken.

Two other local plant associations were frequently encountered and had to be avoided in the study of true succession. Deep wind deposits (D) check grass vegetation and favor *Chenopodium album*, *Sisymbrium altissimnum*, *Helianthus annuus* (common sunflower), and *H. petiolaris* (prairie sunflower), plants whose seeds are laid with the wind deposits. Which of these species dominates depends on local circumstances. Areas of shallow stony soils (E) were usually poorly cultivated; native relicts persisted and rapidly restored a postclimax of mixed short and tall grasses. Besides the principal species, *Buchloe dactyloides* (buffalo grass), *Bouteloua gracilis* (blue grama grass), and *Carex filifolia* (blackroot), f[illegible] taller species were abundant, namely, *Stipa comata* (western needle grass), *Aristida longiseta* (red three-awn), *Andropogon scoparius* (little bluestem), and *Bouteloua curtipendula* (side-oats grama grass). The usual forb associates of the short grassland were present.

Where native species are completely killed, gravelly knolls have considerable *Boebera papposa* (fetid marigold) and *Plantago purshii* (poor Joe). Emphasis is placed on the abnormality of such areas in natural succession and a maximum exclusion of them from quadrat measurements. This is not as readily accomplished as the idealized diagram, Fig. 3, would indicate. Consequently, small amounts of some of these species seem to be out of place in the data.

PAST AND PRESENT LAND-USE FACTORS

Soil management during the period of cultivation exerts some influence on early stages of succession. Of first importance is the length of time of cultivation. Closely related to this are the thoroughness of cultivation and intermittent use as compared to continuous use. The amount of tillage varies with the type of crop grown. These influences are related to the degree of killing out of the grasses Once the grass-roots are dead, there is little additional effect. The last crop grown before abandonment influences the first two or three years of succession because plants differ in their ability to withstand the cutting action of blowing sand on previously cultivated land, whereas this adaptation is not significant on a stubble field.

Present use of abandoned land is ordinarily nonintensive or negligible, and possible exceptions must be allowed for in the study of succession. Under close grazing, short grass may never be attained. The presence of recently abandoned land near an older tract may result in wind deposition and retardation of plant growth The climatic factor, drouth, in this way becomes more important in succession than in climax. Observations in the study area in 1938 revealed *Bouteloua gracilis* persisting as a perfect stand in a native area blanketed by more than an inch of wind-blown materials. *Salsola pestifer* (Russian thistle) plants from 3 to 5 inches high protected the grasses, while shifting sand in adjacent abandoned fallow fields prevented all vegetative growth.

TIME-VARIATION IN SPECIES COMPOSITION ON ABANDONED LAND

Field investigation entailed quadrat measurements on a large number of tracts, but detailed presentation of data for individual tracts is not required for the purposes of this paper. Data from 19 abandoned fields and 3 native areas are summarized in Table 1. Special quadrat studies were made on several other fields, and observations were extended to tracts distributed throughout the county.

ABUNDANCE AND FREQUENCY OF SPECIES

The species are listed in Table 1 in the sequence of their appearance in the succession in appreciable quantities. Abundance and frequency for various years are recorded. The fundamental relationships of the successional species and plant groups, as based on extensive field observations and representative quadrat data, are shown in diagram form in Figs. 4, 5, and 6. Only the major or keynote species for each year will be mentioned in the discussion; the positions and relative

importance of other species are readily found by reference to Table 1. The following eight summary points correspond to eight periods of abandonment; it is clear, however, that weather variations may cause incidental shifts in the rate of entrance and disappearance of a given species. The trends have been verified by observations over

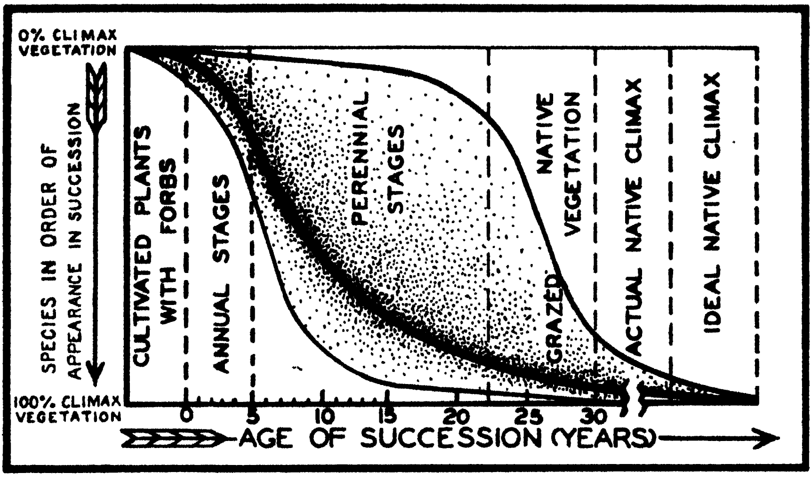

FIG. 4.—Schematic representation of the variety of species and successional stages of vegetation growing on abandoned land shown in relation to grazed native and native climax associations. The data of Table 1 are correlated in this diagram. Height of shaded area indicates variety of vegetation and heavy curve shows trend of predominating species.

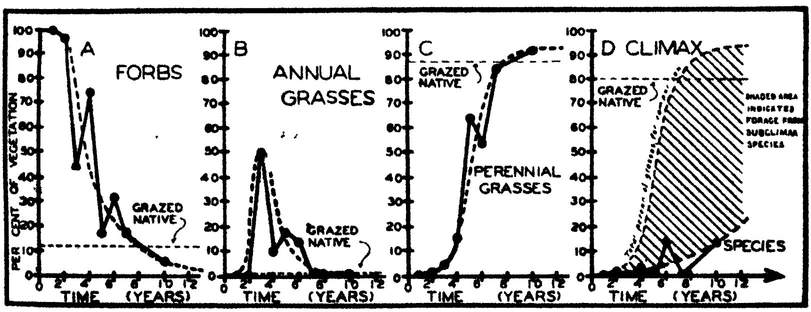

FIG. 5.—Time-variation in the composition of successional vegetation on abandoned land compared to grazed native vegetation. Data expressed as percentages of total number of stems, from Table 2.

broader areas and during a longer time than are represented in the tabulated data.

During the first year, the annual forbs, *Amaranthus retroflexus* (pigweed), *Salsola pestifer*, and *Chenopodium album*, predominate completely. In an individual field, one or the other of these may form 80% or more of total stems. The frequency data show all three species

TABLE 1.—*Abundance and frequency of important species* growing in fields abandoned for periods of time varying from 1 to 10 years or more in comparison to those in native grassland in Kimball County, Nebr., 1935.*†

Species	1 yr., av. 2 fields		2 yrs.,	3 yrs., av. 6 fields		4 yrs., av. 6 fields		5 yrs.,		6 yrs.,		7 yrs.,	10 or more years		Native grass-land, av. 3 fields	
	A	F	A	A	F	A	F	A	F	A	F	A	A	F	A	F
Amaranthus retroflexus L.	**15**	*71*		3	*21*	2	*16*			t	*8*		t	*5*	t	*1*
Salsola pestifer A. Nels.	**36**	*100*	3	2	*40*	11	*67*	1	*29*	8	*58*	t			1	*21*
Chenopodium album L.	**38**	*94*	**54**	5	*68*	11	*73*	4	*74*	8	*70*	1	t	*10*	t	*21*
Salvia lanceolata Willd.	t‡	*4*		t	*4*	1	*7*								t	*1*
Setaria viridis (L.) Beauv.	t	*4*		t	*1*	1	*10*									
Anogra coronopifolia (T. & G.) Britton	1	*8*		t	*3*	1	*11*	t	*6*	t	*2*				t	*5*
Sisymbrium altissimum L.	1	*13*	1	1	*21*	4	*42*	t	*24*	t	*25*				t	*1*
Helianthus petiolaris Nutt.	3	*25*	4	1	*13*	3	*28*	t	*12*	t	*2*	t	1	*45*	t	*8*
Polygonum convolvulus (L.) Dum.	1	*17*		1	*12*	1	*12*			t	*4*					
Lygodesmia juncea (Pursh.) D. Don	2	*20*	3	t	*20*	1	*29*	t	*15*	1	*30*		t	*10*	t	*1*
Polygonum aviculare L.	t	*9*	3	3	*29*	1	*10*	t	*9*	1	*19*	t	t	*10*	t	*3*
Plantago purshii R. & S.	1	*4*	**17**	3	*18*	11	*33*	4	*35*	1	*13*	4	2	*40*	7	*57*
Gaura coccinea Nutt.			2	t	*1*	t	*1*			t	*2*					
Lactuca virosa L.			3	t	*1*											
Lepidium densiflorum Schrad.			3	4	*47*	6	*38*	t	*21*	1	*23*	t	t	*5*	1	*43*
Lappula occidentalis (S. Wats.) Greene			3	9	*67*	**13**	*51*	5	*44*	6	*72*	1			t	*4*
Stipa comata Trin. and Rupr.			2	t	*1*	3	*6*	**42**	*79*	t	*2*	4			1	*7*
Astragalus gracilis Nutt.				t	*2*	t	*2*									
Bromus tectorum L.				**50**	*60*	8	*23*	7	*53*	**14**	*51*	t				
Grindelia squarrosa (Pursh.) Dunal	t	*4*		9	*63*	4	*27*	t	*3*	1	*15*	3	t	*20*	1	*18*

Agropyron smithii Rydb.				4	*18*	6	*18*	**16**	*41*	**35**	*70*	5	1	*10*	2	*43*
Chamaesyce sp. S. F. Gray				t	*1*	1	*8*			t	*2*	t				
Bromus commutatus Schrad.				t	*6*	2	*7*	8	*38*							
Sphaeralcea coccinea (Nutt.) Rydb	t	4		t	*12*	1	*9*	1	*21*	2	*36*	2	t	*10*	1	*33*
Festuca octoflora Walt.				t	*6*	t	*2*	3	*24*				1	*15*	1	*26*
Helianthus annuus L.				t	*1*							1				
Artemisia frigida Willd.			t	2	*16*	1	*8*	t	*9*	t	*9*	3	2	*25*	1	*23*
Sporobolus cryptandrus (Torr.) A. Gray.				t	*1*	1	*4*	t	*3*			1	7	*60*	t	*2*
Schedonnardus paniculatus (Nutt.) Trel.				t	*1*	5	*10*	2	*3*	5	*17*	**74**	3	*20*		
Ambrosia elatior L.				t	*1*	1	*9*	t	*3*				1	*40*	t	*6*
Sitanion hystrix (Nutt.) J. G. Smith				t	*1*	t	*1*	3	*15*			t	t	*5*		
Boebera papposa (Vent.) Rydb.						t	*1*					2				
Aristida longiseta Steud.						t	*1*			t	*2*		**66**	*95*	4	*15*
Polygonum erectum L.						t	*1*			1	*11*					
Juncus sp. L.										2	*4*					
Carex filifolia Nutt										14	*6*				**5**	*51*
Buchloe dactyloides (Nutt.) Engelm.				t	*1*	1	*6*						4	*5*	**23**	*33*
Bouteloua gracilis (H. B. K.) Lag.								t	*3*				10	*10*	**52**	*100*
Total number of quadrats measured	25		22§	167		162		34		53		22§	20		72	
Density of Vegetation (Av. stems per quadrat)	19		44	90		54		110		65		149	148		133	

*Composing 1% or more of the vegetation in at least one field or average of fields.

†Data expressed as abundance (A) (% of total stems), frequency (F) (% of total quadrats in which the species occurred), and as density of vegetation (average number of stems per quadrat of 0.09 sq. m. area).

‡Trace; less than 0.5%.

§Two quadrats of 1.0 sq. m. each, equivalent to 22 quadrats of 0.09 sq. m. each.

Species occurring in one or more fields only as traces are as follows: (1) Abandoned and native fields: *Astragalus mollissimus* Torr., *Camelina sativa* (L.) Crantz, *Eriogonum alatum* Torr., *Opuntia* sp. Hill, *Pentstemon albidus* Nutt., *Psoralea lanceolata* Pursh., *Sideranthus spinulosus* (Nutt.) Sweet; (2) Abandoned fields only: *Allionia linearis* Pursh., *Arenaria hookeri* Nutt., *Cirsium arvense* L. Scop., *Lactuca scariola* L., *Leptilon canadense* (L.) Britton, *Macrocalyx nyctelea* L., *Oryzopsis hymenoides* (Roem. and Schult.) Ricker., *Panicum capillare* L., *Solidago mollis* Bartl., *Tragopogon pratensis* L.; (3) Native fields only: *Gutierrezia sarothrae* (Pursh.) Britton and Rusby, *Lappula lappula* L.

to occur in nearly every quadrat. A few other species appear in small amounts. Volunteer rye and other field crops are not uncommon.

In the second year, all three may persist, but *C. album* persists the most. *Plantago purshii* is the outstanding introduction. Minor species are more numerous.

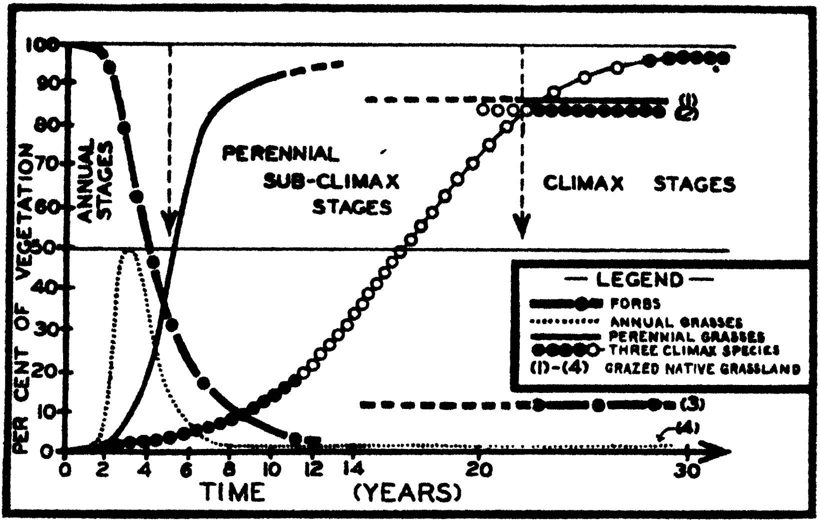

FIG. 6.—Trends in the time-variation of four vegetal classes compared to the composition of grazed native and native climax associations. The trends are taken from Fig. 5 and form the basis of defining the broad stages in this succession.

In the third year, the whole field becomes covered with the annual grass *Bromus tectorum* (downy brome); it forms a stand as complete and uniform as a cultivated crop. An annual forb *Lappula occidentalis* (stickseed) is important but is conspicuous only on gravelly knolls where *B. tectorum* is less well adapted. A host of different species occurs, representative of all stages of the succession except the very last. The third year is still much influenced by the last crop grown before abandonment. The density of *B. tectorum* was found to vary considerably in adjacent fields, being greater on stubble than on previously tilled fields. Little effect of the crop last grown is noticed after the third year.

In the fourth year, *B. tectorum* loses its foothold and *L. occidentalis* increases to greatest abundance. To an even greater degree than before, species from all stages of the succession are represented. The frequency column shows few species present in over half the quadrats: this means the cover is spotted rather than uniform. *Agropyron smithii* is making a small but significant beginning; in the field it appears as scattered patches 5 to 10 feet in diameter.

The most significant change at five years is the marked increase in *A. smithii*. It occurs in nearly half the quadrats and forms one-sixth of the stems. *Stipa comata* appears in more than normal amounts in

the field in which these data were taken. This irregularity is taken into account later in this paper in establishing trends.

The sixth year is the year for best development of *A. smithii*; the values 35 and 70 for abundance and frequency are thought to be minimum rather than average for this wheat grass stage. *Carex filifolia* appears for the first time in substantial amounts. This is the last year *B. tectorum* is of any consequence.

Schedonnardus paniculatus (wild crabgrass) makes a good growth on the seven-year tract. The data are based on a single field and it is believed that on average fields this species does not replace *A. smithii* to this extent.

A field of 10 or 15 years abandonment showed abundant growth of *Aristida longiseta* and 14% of *Bouteloua gracilis* and *Buchloe dactyloides* Small amounts of species from all stages still persist. This field of 20 or 30 acres has been permanently removed from cultivation and is available for observations of further changes. It is located in a square mile of native vegetation. Besides the small quadrat measurements reported herein, two permanent quadrats 1 meter square have been established. These were mapped in 1935 and 1938 and will be periodically mapped for one or more decades.

In grazed native grassland, the three most abundant species form four-fifths of the vegetation. *Bouteloua gracilis* occurs in every quadrat; *Buchloe dactyloides* constitute one-fourth of the stems. Species from all stages of the succession occur in small amounts, and frequencies indicate a fairly wide distribution of them. *Plantago purshii* occurs in 57% of the quadrats and forms 7% of the vegetation. This is in agreement with the usual observations in grazed native grassland.

The density of vegetation (reported at the bottom of Table 1) increased from 19 in the first year to nearly 150 in the older fields The uniform increase is interrupted by the rapid increases of *B. tectorum* in the third year and *A. smithii* in the sixth. An average density of 133 was found on grazed native areas.

The highest values for abundance in Table 1 form a rough line of regression from left to right in the table. The data are further projected, for purposes of illustration, in Figure 4. Annuals begin before abandonment and predominate for four or five years, after which perennials are the more important. The variety of species in a given year is indicated by the height of the shaded area. The diagram emphasizes the early entrance of nearly all the species of the whole succession and their persistence even into moderately grazed native vegetation. Grazing the native vegetation apparently results in increasing the variety of vegetation more or less in proportion to the height of the shaded area in Fig. 4. Climax vegetation has few species surviving from the early successional stages and it is supposed the climax vegetation as modified by moderate grazing would consist largely of the three dominant species.

ABUNDANCE OF PLANT GROUPS

Table 2 shows the abundance of forbs, annual grasses, perennial grasses, and principal climax species calculated by combining abun-

dance of species of Table 1. These data are plotted in Fig. 5. In 5A the drop in forbs at three years is occasioned by the abrupt displacement by annual grasses shown in 5B. The second drop in forbs (5A) at five years is a complement of the sharp increase in perennial grasses (5C), occasioned, as has been pointed out, by an abnormal amount of *Stipa comata* in the fifth-year field. These irregularities are readily eliminated by construction of the broken lines showing trends. These lines showing main trends indicate that the changes in abundance of forbs and perennial grasses are rapid for four to eight years. At 10 years, forbs are less abundant and perennial grasses more abundant than in grazed native areas. Further, the annual grasses come in, flourish, and leave almost completely between the second and the seventh year of succession. The principal species is *B. tectorum*; common also are *B. commutatus* (hairy chess), *Panicum capillare* (witchgrass), and *Setaria viridis* (green foxtail); *Festuca octoflora* (six-weeks fescue) is more common during and after the fifth year. Figure 5D illustrates the slowness and irregularity with which the three principal climax species enter during the first 10 years. The comparison to total perennial grasses emphasizes the rapid rise in forage value of land after the fourth year of abandonment.

TABLE 2.—*Abundance* of various classes of vegetation growing on farm lands abandoned from 1 to 10 years or more, Kimball County, Nebr., 1935-37.*

Time abandoned, years	No. of fields used for average	Forbs %	Annual grasses %	Perennial grasses %	Total† %	Principal climax species,‡ %
1	2	100	0	0	100	0
2	1	98	0	2	100	2
3	6	44	50	5	99	0
4	6	75	10	16	101	4
5	1	18	18	64	100	0
6	1	32	14	54	100	14
7	1	17	0	84	101	0
10 or more	1	7	1	92	100	14
Native (grazed)	3	12	1	87	100	80

*Percentage of total number of stems.
†Percentage of traces added in to reduce accumulative error.
‡*Buchloe dactyloides, Bouteloua gracilis, Carex filifolia.*

In Fig. 6, the trends in the four plant groups (Fig. 5) are combined and projected through a greater period of time on the basis of known points. Again, the corresponding abundance found in grazed native grassland is shown for comparison. This summary graph shows that the perennials become more important than the forbs at about five years and that the annual grasses are sharply declining from their maximum. Subsequent to this time perennial grasses flourish, with only a few perennial forbs in the wetter years. The succession of perennial grasses, involving a gradual replacement of taller grasses by shorter ones is beyond the year-to-year abandonment periods studied in this investigation. Certain observations throw significant light on the replacement processes, and these are now summarized, first with regard to plant-competition for water and then as to the relationships of a number of the perennials to climax vegetation.

PLANT-COMPETITION FOR WATER

At the outset of the succession, the land is partially or wholly without cover, so that water is accumulated in the soil. Were the climax species seeded in the area, they would flourish and succession would be accelerated. Under natural circumstances, seeds from the ever-present annual forbs are the most rapidly disseminated, and a thin stand of vigorously growing plants results. On fruiting, these first year plants give rise to a thick stand the following season. So thick is this stand that the plants compete strongly for the already dwindling water supply and mortality becomes high. Annual grasses, better able to grow and seed in early season on seasonal precipitation, find opportunity to flourish in the third season. Those perennial grasses having most rapid means of propagation are first to begin replacing the annuals. Their great increase comes in the fifth and sixth years. At this time infiltration of water is more rapid and penetration greater than later in the succession, with the result that deeper rooted species are more favored at this stage than later.[6] *Agropyron smithii* is the best example of the species adapted for replacing the annuals; it tolerates extremes of water supply, spreads rapidly by both seed and rhizomes, and is fairly deep-rooted. In the course of time, the soil becomes more compact and infiltration less rapid. Species having shallow rooting habits in addition to an adaptation to withstand extremes of drouth are able to utilize moisture before it reaches the deeper rooted perennials. In this way, *Bouteloua gracilis*, *Buchloe dactyloides*, and *Carex filifolia* replace species of the *A. smithii* type to a large degree and become dominant, particularly where grazing tends to reduce the abundance of the taller grasses (23).

RELATIONSHIP OF SUCCESSIONAL TO CLIMAX SPECIES

Plant associations with *A. smithii*, *Stipa comata*, *Aristida longiseta*, and *Sporobolus cryptandrus* (sand dropseed) appear often in native areas. The climax vegetation for a broad region can be defined satisfactorily only with reference to zonal soils. Thus *A. smithii* appears normally in the succession but is replaced on medium-textured, well-drained upland soils under moderate grazing conditions. It persists indefinitely in drainage ways, pond margins, and on heavy soils. This species enters most rapidly of the perennials and yields the maximum forage of all stages in the succession. *S. comata* similarly is replaced in the normal succession under grazing but persists on coarse-textured soils. This species appears consistently on nearly all gravelly spots in abandoned fields, and thus appears to be better adapted for such a habitat, although accidental seeding and relicts may be responsible for its re-establishment in some cases. It is not uncommon to find *S. comata* spots in a dense field of *A. smithii*. In coarse-textured soils more than a normal supply of water is available, and this accounts for persistence of this taller species. Homestead cultivated areas abandoned 25 or 30 years showed an appreciable amount of *S. comata* and

[6]Data are far from complete on runoff and moisture penetration in various types of grassland. Weaver and Noll (24) and Judd and Weldon (9) furnish data partially applicable to this point.

other taller species, but the cover was more sparse than climax vegetation and the short grasses predominated. *Aristida longiseta* and *Sporobolus cryptandrus* are probably minor species in the true climax. The former was found abundantly at 10 to 15 years abandonment with moderate grazing.

VIABILITY STUDIES WITH NATIVE SPECIES

Seeds from 24 grasses and 15 legumes were collected in Kimball County, in late summer and fall, 1935. The grass seeds were examined for the presence of caryopses by spreading them out in a single layer over a glass plate illuminated from below.[7] This examination raises the germination percentage, because the empty glumes resembling seeds can be removed. The germination was carried out between moist blotters, placed alternately in two germinators. Seeds were kept at 20° C for 18 hours and at 30° C for 6 hours each day. Four lots of about 100 seeds each were used for each species. Scarification with sandpaper was tried for all the legumes and two of the grasses. The results are reported in Table 3 Scarified legumes gave 32 to 83% germination except one species, *Lathyrus ornatus* (showy vetchling). The grasses gave medium to high viability except for three species. After scarification, *Oryzopsis hymenoides* (Indian ricegrass) and *Sporobolus cryptandrus* still showed low viability. The most striking fact is the high viability for practically all species.

AGRONOMIC APPLICATIONS OF STUDY

Shantz (17, 19/21) presented various phases of indicator significance of native vegetation when there was still much unbroken native upland. Information on succession aids in interpretation of present use and use-suitability of land in the Plains region today.

PRESENT LAND-USE AND SUCCESSION

In a typical level upland sample area (7), 87% of the land is or has been cultivated, and in 1935, 24% of the land was abandoned.[8] This means that, at least in some periods, three-tenths of the cultivated land is engaged in various stages of natural revegetation. It is of significance, therefore, that after five years of abandonment, high forage yields are possible. From ¾ to 1 ton of hay per acre is cut from the best wheat grass fields.

All the species in the succession have a significance in the production of cover and roots, which are aids in the control of dust storms, floods, and erosion.

LAND USE-SUITABILITY

It is perhaps inevitable that extensive breaking of grassland will occur during years of high rainfall and high prices. Use-suitability of

[7]Method mentioned by Blake (1) and used by the Soil Conservation Service, Lincoln, Nebr.

[8]Data from the office of the County Agricultural Agent indicate a lower proportion of abandoned land in the county as a whole because extensive rough areas have not been cultivated.

TABLE 3.—*Viability of native grass and legume seeds.*

Grass seeds	Germination Unscarified %	Germination Scarified %	Legume seeds	Germination* Scarified %
Agropyron albicans	69	—	*Astragalus adsurgens*	67
Agropyron smithii	95	—	*Astragalus carolinianus*	47
Andropogon scoparius	87	—	*Astragalus crassicarpus*	28
Aristida longiseta	98	—	*Astragalus drummondii*	37
Bouteloua curtipendula	95	—	*Astragalus gracilis*	74
Bouteloua gracilis	94	—	*Astragalus missouriensis*	50
Bouteloua hirsuta	87	—	*Astragalus mollissimus*	63
Bromus commutatus	52	—	*Astragalus shortianus*	83
Bromus tectorum	75	—	*Lathyrus ornatus*	1
Buchloe dactyloides	67	—	*Petalostemum candidum*	76
Calamovifa longifolia	91	—	*Petalostemum purpureum*	71
Elymus canadensis	95	—	*Psoralea esculenta*	74
Festuca octoflora	90	—	*Psoralea hypogea*	42
Koeleria cristata	74	—	*Psoralea lanceolata*	47
Muhlenbergia cuspidata	1	—	*Sophora sericea*	32
Munroa squarrosa	26	—		
Oryzopsis hymenoides	low	10		
Poa pratensis	92	—		
Schedonnardus paniculatus	100	—		
Setaria viridis	43	—		
Sitanion hystrix	88	—		
Sporobolus cryptandrus	low	1		
Stipa comata	59	—		
Stipa viridula	11	—		

*Unscarified seed gave "low" germination.

the land for less intensive enterprises is indicated when the intensive users fail to earn production costs and abandon the land. Grazing use would be gone except for costly reseeding or natural succession. Severe overgrazing likewise does not satisfy the requirements for continued profitable land-use over a long time because of its destructive effect on both successional and climax vegetation.

Use-suitability of land in this area is not limited directly by lack of soil fertility or soil depth. Misuse of land arises chiefly with an overdevelopment of intensive agricultural enterprises in a region of severe climatic limitations—a short frost-free season of 128 days, hail and wind hazard, and recurrent shortage of sufficient water for cultivated crop production. The inevitable abandonment of land which results periodically sets into operation the processes of natural succession of vegetation.

SUMMARY

This investigation deals with the natural succession of vegetation on previously cultivated, abandoned farm lands in an arid region. The plant communities composing the succession are broadly limited by the climatic and soil conditions. The study was confined to the normal soil on the gently undulating upland so that the effect of these factors would be the same for all fields. The cropping system pre-

ceding abandonment influences the successional vegetation during the first three years.

Beyond these three influences, the time-variation in species composition is controlled chiefly by the changing relationships in the plants' competition for water. During the first five years, annual species predominate. Vigorously-growing annual forbs soon use soil moisture stored under bare ground. Annual grasses flourish in the third year and decline rapidly in the fourth to sixth years. Deeper-rooted, more drought-resistant perennials appear to have an advantage in moisture competition at this stage. *Agropyron smithii* leads the perennial grass entrance, beginning in the fourth year and dominating the whole cover in the sixth. At 10 to 15 years nearly all of the cover is composed of the perennial grasses of which 14% is the climax short grasses. Small amounts of species representative of all stages in the succession persist through this intermediate period. The short-grass species take the water as it begins infiltration into the soil, thus placing the deeper-rooted perennials at a disadvantage, and providing for a gradual return of short-grass sod.

Grazing of native grassland allows an influx of most of the successional species. A larger percentage of forbs occurred in grazed native areas than in fields abandoned 10 years or more. This fact and the wide variety of vegetation in intermediate stages indicate that it is not until the latest period in the succession that the annuals and short-lived perennials are crowded out of the cover. The climax short-grass species made up four-fifths of the grazed native population compared to the 14% on the 10-year field.

A high viability of seed was found for all but 3 of the 24 native grasses tested. Similarly, all but 1 of the 15 native legumes showed high viability, provided the seeds were first scarified with sandpaper.

Natural succession of vegetation is important in the Great Plains from an agronomic standpoint in returning abandoned cultivated lands to forage production. After five years, the yield of grass hay often exceeds 3/4 ton per acre in moderately wet years.

LITERATURE CITED

1. Blake, A. K. Viability and germination of seeds and early life history of prairie plants. Ecol. Monog., 5:405–460. 1935.
2. Britton, N. L., and Brown, A. Illustrated flora of the northern United States and Canada. I, II, III. New York: Scribner's Sons. 1913.
3. Hanson, H. C., Ball, W. S. An application of Raunkiaer's law of frequency to grazing studies. Ecology, 9:467–473. 1928.
4. ————, and Love, L. D. Size of list quadrat for use in determining effects of different systems of grazing upon *Agropyron smithii* mixed prairie. Jour. Agr. Res., 41:549–560. 1930.
5. ————. A comparison of methods of botanical analysis of the native prairie in western North Dakota. Jour. Agr. Res., 49:815–842. 1934.
6. Hitchcock, A. S. Manual of the grasses of the United States. U. S. Dept. Agr. Misc. Pub. 200. 1935.
7. Jackson, M. L., Hayes, F. A., and Weldon, M. D. Some chemical and morphological relationships between soil profiles of the Rosebud and associated soil series in southeastern Kimball County, Nebraska. Soil Sci. Soc. Amer. Proc., 2:437–445. 1937.
8. Judd, B. I. The restoration of grassland conditions in the high plains section of Western Nebraska. (Thesis presented to the Univ. of Nebraska. 1936.)

9. JUDD, B. I., and WELDON, M. D. Some changes in the soil during natural succession of vegetation after abandonment in western Nebraska. Jour. Amer. Soc. Agron., 31. 1939.
10. KENOYER, L. A. A study of Raunkiaer's law of frequence. Ecology, 8:341–349. 1927.
11. MARBUT, C. F. Soils of the Great Plains. Ann. Assoc. Amer. Geog., 13:41–66. 1923.
12. ————. Soils of the United States. U. S. D. A. Atlas of Amer. Agr., pt. 3. 1935.
13. MCGINNIES, W. G. The relation between frequency index and abundance as applied to plant populations in a semiarid region. Ecology, 15:263–282. 1934.
14. MEYER, A. H., VEATCH, J. O., TILLMAN, B. W., HAYES, F. A., MORTLOCK, H. C., and COLLETT, C. E. Soil survey of Kimball County, Nebraska. U. S. Dept. Agr. Bur. Soils. 1917.
15. RAUNKIAER, C. Formationsundersøgelse og formationstatistik. Bot. Tidsskr., 30:20–80. 1909.
16. RYDBERG, P. A. Flora of the prairies and plains of central North America. New York: New York Bot. Garden. 1932.
17. SHANTZ, H. L. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. D. A. Bur. Plant Ind. Bul. 201. 1911.
18. ————. Plant succession on abandoned roads in Eastern Colorado. Jour. Ecol., 5:19–42. 1917.
19. ————. The natural vegetation of the Great Plains region. Ann. Assoc. Amer. Geog., 13:81–107. 1923.
20. ————. Natural vegetation: grassland and desert shrub. U. S. D. A. Atlas Amer. Agr. 1924.
21. ————, PIEMEISEL, R. L. Indicator significance of the natural vegetation of the southwestern desert region. Jour. Agr. Res., 28:721–802. 1924.
22. WEAVER, J. E. Root development in the grassland formation. Carnegie Inst. Wash. Pub. 292. 1920.
23. ————, and CLEMENTS, F. E. Plant ecology. New York: McGraw Hill. 1938.
24. ————, and NOLL, W. C. Comparison of run-off and erosion in prairie, pasture, and cultivated land. Univ. Nebr. Conserv. and Surv. Div. Bul. 11. 1935.

EFFECT OF MUTILATION OF WHEAT SEEDS ON GROWTH AND PRODUCTIVITY[1]

W. J. SANDO[2]

WHEN wheat is threshed some of the grains are usually broken. This damage in very dry wheat frequently exceeds 2% and may amount to more than 10%. The value for seeding purposes of the germ end of broken grains is of interest to the farmer.

Obviously, the fragments without embryos are a total loss in seed grain. If, as has often been stated arbitrarily, in the formation of the seed nature supplies food reserves in considerably greater quantities than is necessary to insure a normal development of the seedling up to a stage at which it is capable of independent support, then within limits fragments of grains containing embryos might be expected to produce normal plants. There is evidence, however, that the removal or reduction of the food reserves of the seed results not only in a deleterious effect upon the early growth of the seedling but also in impaired subsequent development.

Extensive experiments have been carried on by various investigators to determine the effects upon the germination of seeds and the subsequent development of the resulting plants when portions of the seed have been removed. These experiments, however, have dealt principally with embryos devoid of endosperm and few have been carried on entirely in the field or continued up to the maturity of the plants.

This article presents the results of field plantings of winter wheat seeds from which different portions of the endosperm were removed, together with additional observations on plantings made in greenhouse flats.

REVIEW OF LITERATURE

Andronescu (1)[3], Blociszewski (4), Bonnet (5), Brown (6), Brown and Morris (7), Dubard and Urbain (10), Sachs (14), Stingl (15), and Van Tieghem (16) found that the endosperm was not indispensable for the germination of the embryo or for the early development of the young plant.

Cronbach (8) found a higher and more rapid germination in half kernels than in whole kernels of wheat.

Delassus (9) and Wollney (17), as quoted by Brown (6), experimenting with kernels of vetch, beans, peas, lupines, and rye having various proportions of the seed attached to the embryo, found the plants produced from whole seeds superior in development.

Although the present study deals with mutilated seed, the possible bearing on the size of seed is obvious. Kiesselbach and Helm (13) carried on experiments to determine the relation of size of seed to yield and reviewed the extensive literature dealing with size of seed. The later work of Arny and Garber (2), Kidd and West (11, 12), and of Bayles (3) is of interest. In general, these investigators report

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[2]Agronomist.
[3]Figures in parenthesis refer to "Literature Cited", p. 565.

a significant and in many cases a high degree of correlation between size of seed and size of the young plant and usually also a high correlation between size of seed and yield per plant and between size of seed and yield per acre in spaced plantings. When equal quantities of seed per acre rather than equal numbers have been used, no differences in yield have been observed or they have been very small and of no practical importance.

MATERIALS AND METHODS

Uniform, plump kernels of two varieties of winter wheat, Dawson and Nittany, were cut transversely with a razor blade, approximately half the seed being removed from some lots and about two-thirds from the other lots of each variety. The ends containing the germs were then grown in the field at the Arlington Experiment Farm, Arlington, Va. The experiment was carried on in the three years 1933, 1934, and 1935. To determine the possible effect of micro-organisms attacking the exposed ends of the kernels, a portion of the cut kernels were carefully capped with a film of paraffin for comparison with the unparaffined seeds.

Whole and cut kernels were equispaced in 5-foot rows 1 foot apart. At harvest all the plants were pulled, weighed individually after removing the roots, and then threshed. The size and arrangement of the field experiments varied slightly in the different years.

In addition, whole and divided wheat kernels of the spring variety, Baart, were planted in greenhouse flats containing either sterilized or unsterilized soil, to determine further any injurious effect of soil-borne organisms on the cut seeds as well as to observe differences in germination and in the development of the plants at different stages. The flats were 12 inches wide, 24 inches long, and 3.5 inches deep. Three rows each of whole, half, and third kernels were planted to a flat, at the rate of 21 kernels per row.

FIELD EXPERIMENTS

The first experiment consisted of four-row block plantings of whole and half seeds of the Dawson and Nittany varieties. Twenty-five whole or half kernels were equispaced in each row on October 12, 1933. The whole seeds of both varieties showed a decided advantage over the half seeds. As an average for the two varieties the whole seeds produced 25.4% more plants and 50% more grain per plant than the half seeds.

In 1934 a total of 127 5-foot rows were planted, 67 of Dawson and 60 of Nittany. Since the results from the two varieties were similar, the data are combined in Table 1. Twenty-five whole or fragmentary kernels were equispaced in each row. The plantings made in the field on October 13 were as follows: (a) Whole, half, and one-third kernels of Dawson and Nittany in alternate three- or four-row blocks. (b) Whole and half kernels of the same varieties in alternate rows.

In Table 1 a distinct and consistent advantage of whole over half seeds is shown and the half kernels were superior to the one-third kernels in all the treatments.

The half and one-third kernels were slower in germinating and the plants were less vigorous than those from whole seeds. The difference in vigor of seedlings is shown by the percentage of the plants that had reached the two-leaf stage. Half seeds produced a higher percentage

of two-leaf plants than did the plants from one-third seeds and whole seeds produced the highest percentage of two-leaf plants.

TABLE 1.—*Plant development from whole, half, and one-third kernels of Dawson and Nittany winter wheat sown October 13, 1934.*

Portion of seed	No. of rows planted	Germination %	Plant survival %	2-leaf plants on Nov. 3 %	Seeds producing mature plants %	No. of culms per plant	Av. weight per plant: Total, grams	Av. weight per plant: Grain, grams
				Grown in Separate 3- or 4-row Blocks				
Whole..	60	87.0	82.7	41.5	72.0	4.7	13.8	3.5
Half	20	79.1	63.0	11.9	49.8	3.6	9.4	2.2
One-third	15	59.4	9.0	1.4	5.3	1.6	2.9	0.9
				Grown in Alternate Rows				
Whole	16	91 2	94.5	45.7	86 2	5.8	16.1	4.4
Half	16	81.7	62.7	11.6	51.2	3.2	7.6	2.0

In 1935, a total of 77 5-foot rows were planted, 20 of Nittany and 57 of Dawson. Twenty whole or partial kernels were planted equispaced in each row. The plantings were made in the field on October 13 as follows: (a) A single block each of whole, half, and one-third kernels. The blocks consisted of 12 rows of whole kernels, 9 rows of half kernels, and 8 rows of the one-third kernels. (b) Nine single rows each of whole and half kernels planted alternately. (c) Five single rows each of whole, half, and one-third kernels planted alternately. (d) A five-row block of whole seed and a two-row block of paraffined one-third seeds grown adjacent to an eight-row block of paraffined half kernel plantings. Sixteen rows of unparaffined half kernels were included for comparison with the paraffined half kernels.

Because of the similarity of the results of the two varieties, the data were combined and the results are presented in Table 2. A comparison of the data in Table 2 shows with one exception a consistent advantage of the whole seed plantings over the half and one-third seed plantings while the half-seed plantings were superior to those from one-third seeds.

The small differences exhibited between the whole, half, and one-third seeds sown in blocks (Table 2) may be attributed to the unfortunate use in this experiment of a plot of land later found to be somewhat inferior in fertility near the ends. The plantings of the other treatments in this experiment were made in a more fertile soil.

It will be noted that plant survival, culms per plant, weight of plant, and weight of seed per plant from plantings of half kernels with paraffined ends were greater than from plantings of half kernels without paraffined ends. This greater injury suggests the invasion of the seed pieces by organisms through the exposed unparaffined ends. From the germination results it appears that the embryos were not injured by parasitic organisms in the early stages of their development but some injury to the mature plants is indicated.

TABLE 2.—*Plant development from whole, half, and one-third kernels of Dawson and Nittany winter wheat sown October 13, 1935.*

Portion of seed	No. of rows planted	Germination %	Plant survival %	Seeds producing mature plants %	No. of culms per plant	Av. weight per plant Total, grams	Av. weight per plant Grain, grams
			Grown in Blocks of Rows				
Whole	12	89.5	95.3	85.4	4.4	15.1	4.7
Half	9	88.3	90.6	80.0	3.9	13.5	4.0
One-third	8	75.0	70.0	52.5	3.8	12.8	3.7
			Grown in Alternate Rows				
Whole	9	95.0	96.5	91.7	6.3	23 2	7.4
Half	9	86.6	87.6	78.9	3.7	12 1	3.6
			Grown in Alternate Rows				
Whole	5	94.0	98.9	93.0	7.1	28.4	8.7
Half	5	82.0	93.9	77.0	4.8	17.8	5.3
One-third	5	47.0	74.6	35.0	2.6	11.8	3.3
			Paraffined Half Kernels Sown Adjacent to Whole and Unparaffined One-third Seeds (Dawson only)				
Whole	5	86 0	86.0	74.0	7 1	21.6	6.9
Half	8	82.5	92.4	76.2	4.9	14.5	4.7
One-third	2	92.5	83.8	77.5	4.3	13.1	4.0
			Unparaffined Half Kernels of Dawson				
Half	16	86 6	89.5	77.5	4.0	13.9	4.1

The average weight of grain per plant from half kernel plantings in three experiments was 33.3%, 46.8%, and 36.5% less, respectively, than from whole kernel plantings and in two experiments the average weight of grain per plant from one-third kernels was 73.9% and 45.8% less, respectively, than that from whole seed.

The results from field plantings of fractional kernels indicate that the seedling is set back so severely in its initial growth that full development rarely occurs.

Some of the reduction in the germination of the fractional portions of seeds planted in the field was due to the weakened condition of the plants which prevented their emergence. Several malformed plants were detected which failed to break through the soil crust.

All of the experiments in the field were conducted under conditions in which some winterkilling was possible. Since the plants produced by half and one-third seeds were less vigorous than those produced by whole seeds, they probably were more susceptible to winter injury. This damage is indicated by the greater mortality of the plants and also by the reduced weight, yield, and number of culms of the plants that survived.

GREENHOUSE EXPERIMENTS

A single flat containing sterilized soil was seeded to three rows each of whole, half, and one-third seeds of the spring variety Baart. The

plants emerged three days after seeding and no injury by parasites was observed.

The plants three days after emergence are shown in Fig. 1. Distinct differences between the plantings may be seen. In general, the

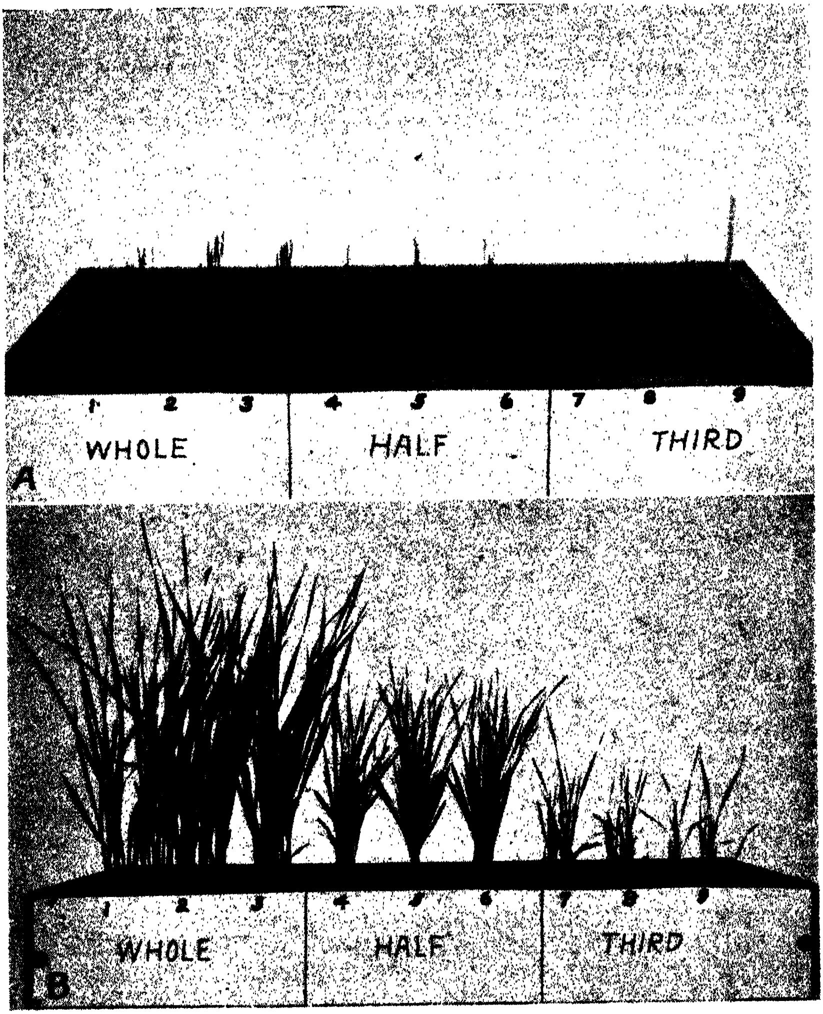

FIG. 1.—Plants from whole, half, and one-third wheat kernels *above*, grown in sterilized soil, 3 days after emergence; *below*, unsterilized soil 13 days after emergence.

plants from the whole seeds appeared very uniform while those from the half seeds were neither as uniform nor as tall as those from the whole seeds. The plants from the one-third seeds were decidedly more nonuniform, more slender, and shorter than those from half

seeds, and showed considerable distortion. The germination percentages of the whole, half, and one-third seeds were 94.4, 96.2, and 66.6, respectively. No plants from the whole seed plantings died after emergence, but the mortality in the half and one-third seed plantings was 1.9% and 11.1%, respectively.

The plants from the various treatments headed two days apart; those from the whole seed headed first and those from the half and one-third seeds followed in order. Measurements of each plant at two-day intervals were made as soon as the plants appeared above the ground. These measurements are illustrated graphically in Fig. 2.

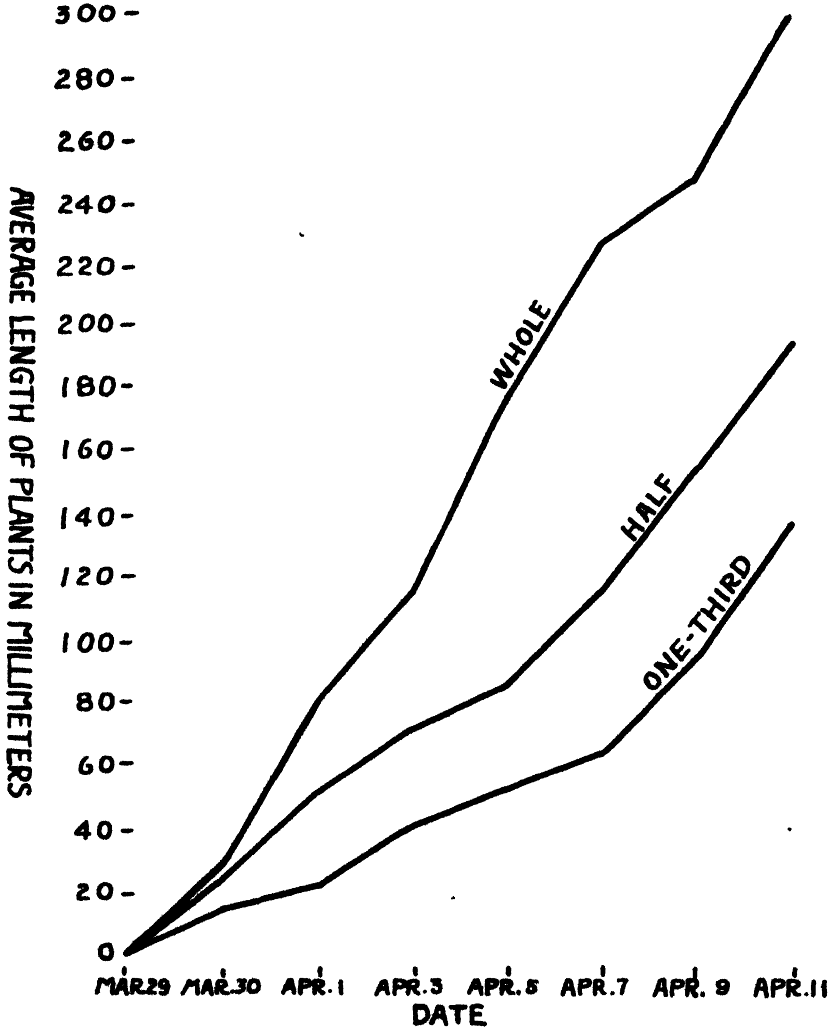

FIG. 2.—Length of plants from whole, half, and one-third seeds sown in sterilized soil.

The growth was greatest in the plants from whole seeds during the period when measurements were made, but this higher growth rate was not maintained to maturity.

A second flat containing unsterilized soil was planted with whole, half, and one-third kernels of the variety Baart. The germination percentage of the whole, half, and one-third seeds was 100, 92, and 74.6, respectively. The mortality of the plants was for the whole, half, and one-third seeds 4.8%, 6.9%, and 29.8%, respectively.

Fig. 1 also shows the plants when 13 days old. In general, the relationships between the various groups are similar to those grown in the sterilized soil. Some plants from one-third seeds in the unsterilized soil, however, showed injury by soil parasites. On March 22, four days after emergence, the average length of the plants grown in unsterilized soil was for the whole, half, and one-third seeds 111.5, 82.2, and 32.5 millimeters, respectively.

Additional data were taken at maturity on the plants referred to above, but the plants were so obviously distorted, owing to close planting, border influence, and the small size of the container (which prevented normal development of the plants), that no reliance could be placed on the measurements.

In the greenhouse the plants were grown in a light, loamy soil that produced no surface crust, but a few plants from the one-third seeds were observed to have difficulty in emerging.

In general, these greenhouse experiments with spring wheat confirmed the results from the field plantings of winter wheat, but a higher percentage of plants survived in the greenhouse than in the field.

In sand-box trials, in which conditions were undoubtedly more favorable than in the field experiments, Cronbach (8) reported a considerable advantage in germination of the clipped (half kernels) over that of the whole seed. In only one test did the writer observe the germination of fragments of seeds to be greater than that from whole seeds.

SUMMARY

Whole kernels and germ-end sections of half and one-third kernels of Dawson and Nittany winter wheats were planted in rows in the field at the Arlington Experiment Farm, Arlington, Va.

Whole kernels were superior to half and one-third kernels in germination and in subsequent plant survival, number of culms per plant (with one exception), total weight per plant, and grain yield per plant. Half kernels likewise were superior to one-third kernels except in one experiment involving too few one-third kernels.

Except in seed germination and in percentage of seeds producing mature plants, half kernels, the cut ends of which were capped with paraffin, were superior to unparaffined half kernels.

Whole, half, and one-third seeds planted in flats containing sterilized and unsterilized soil in the greenhouse in general confirmed the results of the field plantings, although the differences were not so marked owing in part to the crowded condition of the plants which prevented optimum development. In the unsterilized soil the plants

from one-third seeds appeared to be slightly injured by soil-borne organisms.

LITERATURE CITED

1. ANDRONESCU, D. I. Germination and further development of the embryo of *Zea mays* separated from the endosperm. Amer. Jour. Bot., 6:443-452. 1919.
2. ARNY, A. C., and GARBER, R. J. Variation and correlation in wheat, with special reference to weight of seeds planted. Jour. Agr. Res., 14:359-392. 1918.
3. BAYLES, B. B. Influence of environment during the maturation on the disease reaction and yield of wheat and barley. Jour. Agr. Res., 53:717-748. 1936.
4. BLOCISZEWSKI, T. Physiologische Untersuchungen uber die Keimung und weitere Entwickelung einiger Samentheile bedecksamiger Pflanzen. Landw. Jahrb., 5:45-161. 1876.
5. BONNET, C. Recherches sur l'usage de feuilles dans les plantes et sur quelques autres sujets relatifs à l'histoire de la vegetation. Gottingen and Leyden. 1754.
6. BROWN, E. B. Effects of mutilating the seeds on the growth and productiveness of corn. U. S. D. A. Bul. 1011. 1922.
7. BROWN, H. T., and MORRIS, G. H. Researches in the germination of some of the Gramineae. Jour. Chem. Soc., 57:458-528. 1890.
8. CRONBACH, J. Conservation of seed wheat. Oakland City College [Indiana] Bul. 45. 1922.
9. DELASSUS. Influence de la suppression partielle des reserves de la graine sur le developpement de la plante. Compt. Rend. Acad. Sci., 153:1494-1497. 1911.
10. DUBARD, M., and URBAIN, J. A. De l'influence de l'albumen sur le developpement de l'embryon. Compt. Rend. Acad. Sci., 156:1086 1089. 1913.
11. KIDD, F., and WEST, C. Physiological pre-determination: The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. I. The effects of soaking seeds in water. Ann. Appl. Biol., 5:1-10. 1918.
12. ———, ———. Physiological pre-determination: The influence of the physiological condition of the seed upon the course of subsequent growth and upon the yield. II-IV. Review of literature. Chapters I-III. Ann. Appl. Biol., 5:112-142; [157]-170 ;220-251. 19.8.
13. KIESSELBACH, T. A., and HELM, C. A. Relation of size of seed and sprout value to the yield of small grain crops. Nebr. Agr. Exp. Sta. Res. Bul. 11. 1917.
14. SACHS, J. Zur Keimungsgeschichte der Graser. Bot. Ztg., 20:145-151. 1862.
15. STINGL, G. Experimentelle Studie uber die Ernahrung von Pflanzen Embryonen. Flora, 97:308-331. 1907.
16. VAN TIEGHEM, P. Recherches physiologiques sur la germination. Ann. Sci. Nat., (5) 17:205-224. 1873.
17. WOLLNEY, E. Untersuchungen uber die künstliche Beeinflussung der inneren Wachstumsursachen. VII. Der Einfluss des Vorquellens des Saatgutes auf die Entwickelung und Ertrage der Kulturpflanzen. Forsch. Geb. Agr.-Phys., 8:380-391. 1886.

NOTES

GERMINATION OF CARPET GRASS SEED

IN August, 1935, the late H. N. Vinall of the Division of Forage Crops and Diseases, Bureau of Plant Industry, requested that the Division of Seed Investigations, Bureau of Plant Industry, determine the germination requirements of seed of carpet grass (*Axonopus affinis* Chase). He also desired to know whether freshly harvested seed went through a dormant period, and the rate of loss of life of the seed under laboratory storage. Two samples of seed were furnished by Mr. Vinall for this study. One was from the 1934 crop (FC No. 13750, DSI No. 271304) and the other from the 1935 crop (FC No. 13749, DSI No. 271303). The heavy florets containing caryopses were separated with a laboratory blower, and the seed thus cleaned was used for germination studies. The 1934 crop sample contained approximately 73% heavy florets, and the 1935 crop sample approximately 40%.

Various temperature alternations were used. In presenting the results, the first temperature of a pair, e g , 20° to 35° C, was maintained for approximately 17 hours daily and the second one for approximately 7 hours daily. In the condition "Room-35° C", the tests were placed in a north window of a room at approximately 20° from 4 p.m. until 9 a.m. and were kept in a chamber maintained at 35° for the remainder of the 24 hours.

For germination, the seeds were placed on paper towel discs in Petri dishes. The paper was moistened with tap water or with 0.2% potassium nitrate solution, as indicated. The results are averages of duplicate tests of 100 seeds each; half per cents were raised to the next higher per cent.

Germination tests made in September and October, 1935, under various conditions indicated 20° to 35°, and Room-35°, to be the most favorable conditions. However, when potassium nitrate was used to moisten the substratum, the final germination was equally good at 20° to 30° (with light at 30°), but the rate of germination was much slower. When water was used to moisten the substratum, the final germination at 20° to 30° was about 10% lower. The alternations 15° to 25° and 35° to 20° gave somewhat lower results. There was very little germination at 35° to 15°. Seed of the 1935 crop placed on a moist substratum at 35° for 7 days was made dormant so that, when transferred to 15° to 25°, the germination was much less than when tests were placed immediately at 15° to 25°. Chilling the moist seed for 7 days at 3°, 10°, or 15° before germination at 20° to 35° and 20° to 30° did not improve germination.

Tests were made of each sample at 20° to 35° and Room-35° with water and with potassium nitrate each month (with two exceptions) from September 1935 through December 1936. An additional test was made in October 1938. The averages of all tests for each of the above four conditions are shown in Table 1. There would seem to be no reason for suspecting superiority of any of the four methods. Experience with other samples indicates that occasional samples require exposure to light and the use of potassium nitrate for prompt and complete germination of the viable seed.

TABLE 1.—*Average germination of 15 successive tests of two samples of seed of carpet grass at four conditions.*

Seed crop	20°–35° C		Room—35° C		Average %
	Potassium nitrate %	Water %	Potassium nitrate %	Water %	
1934	54 28	55 71	54 14	55 14	54.817
1935	87 00	87 00	86 78	88 07	87.21

The average results of the 800 seeds tested in successive months are shown in Table 2. The results for September, 1935, represent only 400 seeds The 1935 seed maintained its viabiltiy well over the entire 3-year period, although there is an indication of slight loss of viability after about 9 months There is a suggestion from the results, but not definite proof, that there was a slight improvement in germination for several months after harvest

TABLE 2 —*Average germination of two samples of carpet grass seed tested over a period of 3 years*

Date of test	Percentage of germination	
	1934 crop seed	1935 crop seed
Sept. 11, 1935	67	90
Oct 12, 1935	68	86
Nov. 12, 1935	67	88
Dec 16, 1935	64	88
Jan 15, 1936	64	89
Feb 15, 1936	65	87
Mar. 18, 1936	60	90
May 16, 1936	57	91
June 20, 1936	63	93
July 14, 1936	59	85
Aug 24, 1936	50	87
Oct. 2, 1936	53	86
Nov 5, 1936	45	83
Dec 16, 1936	46	84
Oct 12, 1938	5	81

The 1934 seed when received approximately one year after harvest germinated much less than the 1935 seed after storage in the laboratory for 3 years. Also, the 1934 seed began to lose further in viability about 18 to 20 months after harvest and had lost its viability almost completely 3 years after it was received These differences probably indicate injury to the 1934 seed by unfavorable storage conditions previous to its receipt in the laboratory, although the original germination of this sample is not known. Presumably, this previous storage was in a warehouse at the region of production in Mississippi.—EBEN H. TOOLE and VIVIAN KEARNS TOOLE, *Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

AGROBIOLOGIC SURVEY OF PERUVIAN CROPS

SOMETIME ago the writer suggested to various experiment stations in this country and abroad the desirability of comprehensive agrobiologic surveys of the yielding abilities of staple crops in their territories. Such surveys include the following:

1. Collection of regional statistics of average yields of staple crops, showing to what extent the average farmers of the region are exploiting the inherent yielding abilities of the species they are cultivating.

2. Collection of authentic data on exceptional yields of the same crops. Such data show what the species under cultivation are really capable of doing when, by accident or design, they have been provided with especially favorable conditions for growth. Particular search is made for "record" yields, i. e., the largest known yields per unit of land surface given by each kind of crop in the region. These record yields are considered to represent what the crop plants in question may be expected to yield if and when the farmers learn to duplicate the conditions under which the record crops were obtained. A record yield in one year may be exceeded in a following year; the latest record is presumed to represent the actually realizable yielding ability or "quantity of life" of that crop plant.

3. Analysis of *normally grown* crop plants to determine nitrogen percentage in the total dry substance (stalks, leaves, and fruit). Note is simultaneously taken of yield of total fresh substance and total dry substance. By "normally grown" is meant that the plants are cultivated in a non-toxic soil which is known to be supplied with all essential plant nutrients in fairly balanced proportions and with due regard to agrobiologic uniformity of stand. The nitrogen percentage, n, so obtained is inserted in the agrobiologic yield formula $358/n$; the quotient is the theoretical perultimate or maximum possible yield, in kilograms of dry substance per hectare, which a particular species is capable of giving in any event.

Such agrobiologic surveys indicate three things, *viz.*, (1) the present average level of agronomic efficiency of the region, (2) the attainable level of agronomic efficiency corresponding to the real capabilities of the crop plants as demonstrated in their record yields, and (3) the ultimate limit of the productivity of each species or variety deduced through the inverse yield/nitrogen law. The second item above sets a mark of efficiency for the farmers and the agronomists to aim at and is a reference point by which to measure agronomic success. Comparison of the record yield with the indicated perultimate yield will indicate the width of the margin within which future record yields may be enlarged, either by further improvement in cultural conditions or by further selecting.

To illustrate, I am permitted to quote some initial results of an agrobiologic survey of Peruvian agriculture which is being conducted by Professor José Carreras G. of the National College of Agriculture, La Molina, Lima, Peru.[1]

[1]Prof. Carreras' studies are currently published in *Agronomia* (Lima). See especially Vol. 3, No. 15.

SUGAR CANE

Six varieties of sugar cane were comparably grown at the La Molina Station. Observed and calculated data are given in Table 1. Measures are given in metric units.

TABLE 1.—*Agrobiologic data of six cane varieties.*

Variety	Millable cane, tons/ha	N in whole dry substance %	Relative yield, POJ 2878 = 1	Millable cane %	Dry substance in whole plant %	Theoretical perultimate yield of millable cane, tons/ha.
	I	II	III	IV	V	VI
POJ 2878	178.4	0 285	1 000	72	30	301.5
POJ 2714	170 3	0 290	0 954	72	31	286.8
POJ 36 M	168 7	0 290	0 945	68	31	270.4
BH 10(12)	158 2	0 306	0 886	70	32	255.7
Cristalina	145 5	0.318	0 815	66	30	247 5
Bourbon	127 6	0 356	0 715	65	31	210.7

Comparison of the figures in columns I and II shows that the yields of millable cane are inversely proportional to the percentage of nitrogen in the dry substance of the whole plant. This conforms to the general inverse yield/nitrogen law that the smaller the normal nitrogen content of a plant species the greater is its potential yielding ability, or quantity of life. Nitrogen percentage determined on total dry substance is therefore a direct index of the potential vital vigor of sugar cane varieties. This is a rule given by direct observation and does not depend on any theory.

Application of the agrobiologic yield formula $358/n$ ranks these varieties in the same order as direct observation. Taking the data relating to POJ 2878, the perultimate yields (column VI) are calculated as follows: $358/0.00285 = 125{,}614$. The figure 125,614 is the perultimate yield of dry substance in kilograms per hectare. Dividing 125,614 by 0.30 (column V) and multiplying by 0.72 (column IV), we have $(125614/0.30) \times 0.72 = 301473$ kg, or 301.5 metric tons of millable stalks per hectare.

The figures in column VI of Table 1 represent the maximum expectation of yield if all growing conditions are furnished in perfect order. To see how nearly these perfect conditions have been approached, by accident or design, it remains to collate data on record yields. The record cane yields so far collected by Professor Carreras are given in Table 2. The yields here stated are commercial yields from areas greater than one *fanegada* (1 *fanegada* = 2.86 hectares = 7.06 acres).

Under experimental conditions at the La Molina Station the variety POJ 2714 has yielded up to 682 tons/fgd., corresponding to 82.3% of the perultimate. The data so far received from Professor Carreras do not specify a record yield for the Bourbon variety, but he states that in trials in the Lambayeque, Zaña, and Chicama valleys Bourbon consistently trails the other varieties.

TABLE 2.—*Record cane yields in Peru.*

Variety	District	Yield, tons/fgd.	% of perultimate
POJ 2878	Valle de Lambayeque	605	69.6
POJ 36 M	Valle de Lambayeque	615	78.5
BH 10(12)	Valle de Pativilca	565	76.4
Cristalina	Valle de Chicama	568	79.4

Looking next at the ordinary results of cane production throughout the country, the average yield of millable cane for all Peru (including all varieties) is 112 metric tons per hectare (320 tons/fgd.). Assuming 0.32% as the average nitrogen content, the theoretically possible average yield is 246.1 metric tons (771.3 tons/fgd.). By and large Peruvian cane agriculture shows a theoretical agronomic efficiency of 45.5%. If the comparison is based not on the theoretical but on the demonstrated record yield from a commercial field (POJ 36 M, 615 tons/fgd.), the actual efficiency is 52%. This means that the Peruvian sugar cane agronomists, in so far as they may be able to imitate the conditions under which the record yields have been obtained, may expect practically to double their harvests from the same area.

Thus the practical Peruvian agronomists and their research organizations have had set before them a definite mark at which to aim. So long as this mark is not approached they can hardly regard their work as 100% perfect, and the existing differences between the recorded and the theoretical maxima indicate that new records may be hung up and new objectives established.

New vistas are also opened to the geneticists and the plant breeders. Since it is obvious that lower nitrogen content correlates with higher potential yielding ability, it is a natural suggestion to breed and select new seedling canes on the basis of smaller and smaller nitrogen percentages.

COTTON

The agrobiologic potentialities of Peruvian cotton are calculated as follows:

Nitrogen in dry substance, whole plant	2.20%
Dry substance of fresh plant	60.00%
Clean fiber of whole plant	9.00%

The theoretical perultimate yield of total dry substance in kg/ha. is 358/0.022 = 16,272, corresponding to a yield of 2,411 kg/ha. of fiber. The average yield of fiber in Peru is 552 kg/ha., which represents a presumptive agronomic efficiency of 22.6%. The record yield is 1,058 kg., or 43.3% of the theory. This is considerably lower than records established in the United States and elsewhere, but it indicates that cotton production in Peru might be nearly doubled through improvement of growing conditions. Beyond that there is presumably a wide margin for improvement in varieties.

WHEAT

Agrogiologic data for wheat are given as follows:

Nitrogen in dry substance, whole plant..........	1.52%
Dry substance in whole plant........	70.00%
Proportion of clean wheat..........	38.00%

The perultimate yield of wheat of that nitrogen content is 12,785 kg/ha. The average for all Peru in 1936 was 765 kg., corresponding to 5.9% of the theoretical possibility. However, in that year the average yield in the best wheat province, Arequipa, was 3,310 kg., indicating a presumptive agronomic efficiency of 25.9%. During the same year a record wheat yield of 8,433 kg/ha., or 125 3 U. S. bushels per acre, was obtained at the Arequipa branch Station, corresponding to an agronomic efficiency of 65.9% of the perultimate. Evidently, the wheat growers of Arequipa and their agronomists have before them a high mark to reach.—O. W. Willcox, *Ridgewood, N. J*

BOOK REVIEWS

CONSERVATION IN THE UNITED STATES

By A. F. Gustafson, H. Ries, C. H. Guise, and W. J. Hamilton, Jr. Ithaca, New York: Comstock Publishing Company, Inc 430 pages, illus. 1939. $3.

CONSERVATION of natural resources is so broad a field that one author can scarcely cope with it effectively. In this book the collaboration of four authors has produced an excellent non-technical presentation of the subject. The information is pertinent, and the numerous illustrations that enliven the pages add unquestionably to the educational value of the book.

The text is divided into four parts under separate authorship. Part I is concerned with soil and water resources; Part II with forest, parks, and grazing lands; Part III with wild life; and Part IV with mineral resources. Each of these major divisions defines the importance and extent of the resources under discussion, their use, misuse, and relative depletion. Conservation measures are presented. An introduction to the book contains a brief history of depletion and conservation in the United States.

A list of selections for supplementary reading and questions at the close of each chapter adapt the book to classroom instruction. (C. S. S.)

STATISTICAL TECHNIQUE IN AGRICULTURAL RESEARCH

By D. D. Paterson. New York: McGraw-Hill Book Co. X +263 pages, illus. 1939. $3.

THIS book is designed to give the research worker an elementary training in the design of field experiments and is intended as an introduction to more advanced works on this subject. Naturally some knowledge of statistical mathematics and fundamentals is necessary before a student can plunge into experimental design. The

author has devoted six chapters (155 pages) to laying the mathematical foundation for understanding the three chapters (86 pages) on plot technic.

Some idea of the scope of the work may be secured from a list of the chapter titles. They are as follows: General Principles (in which are treated such subjects as means, standard deviation, normal curve of error, standard error, analysis of small samples, basic formulas, etc.), Analysis of Variance, Goodness of Fit and Contingency Tables, Diagrams, Correlation (including total, partial, and intraclass correlation), Regression, Field Experiments (in which are discussed general principles, randomized blocks, Latin squares, orthogonality, etc.), Serial and Perennial Crop Experiments, and Recent Developments in Field Experimentation (including complex and split-plot experiments, uniformity trials, confounding of treatment effects, etc.).

A selected bibliography, an index, and an appendix of seven statistical tables complete the volume. The seven tables are those of x, t, 5 Per Cent Points of the Distribution of z, Chi Square, Napierian Logarithms, F, and Number of Replicates Necessary to Give Significant Differences.

The book is very well written and it is surprising what a wealth of material the author has condensed in the small amount of space. Each topic is illustrated by a numerical example worked out in detail. There are, however, no practice examples for students. The examples in the first six chapters are from animal husbandry, agronomy, and plant pathology which show the applications of the methods to a variety of agricultural problems.

One warning may be advisable; by condensing so many of the fundamentals of statistics in the first chapter, there is danger that the student will look upon the calculations as the essential part of the subject and will not grasp the full significance of such fundamental aspects as homogeniety of the population, valid methods of sampling, randomization, etc. This mistake can be avoided if the student will note that the writer has covered these subjects briefly and if he will take the writer's advice and augment this information by study of works mentioned in the bibliography. The press work and binding are excellent. The book should be on the desk of every student who is interested in field experiments. (F. Z. H.)

INTRODUCTION TO QUANTITATIVE AGRICULTURAL CHEMISTRY

(Anleitung zum qualitativen agrikulturchemischen Praktikum)

By Georg Wiegner. Second edition prepared by H. Pallmann. Berlin: Gebrueder Borntraeger Verlagsbuchhandlung. XIX+ 389 pages, illus. 1938. RM 19.20.

WIEGNER'S "Praktikum" would undoubtedly be as popular in this country as it is in Europe were it not for the fact that the students to whom it may be of most value here are usually not prepared to use a German text. In this second, little-changed edition a few chapters have been omitted or replaced to bring the material up to date. The first 99 pages contain the chemical methods used in con-

nection with agricultural products. In the remainder of the book a detailed discussion is given of the analysis of various agricultural materials and products, such as feed and fertilizers, soils, milk products, and sweet and fermented fruit juices.

The greatest value of this handbook lies in the fact that complete description of the methods is given in such a manner that students who had training in elementary chemistry but have no knowledge of analytical chemistry may prepare themselves for the analysis of agricultural products A 25-page name and subject index increases the usefulness of the volume. (Z I. K.)

SOIL ANALYSIS: A HANDBOOK OF PHYSICAL AND CHEMICAL METHODS

By C. Harold Wright. London: Thomas Murby & Co. Ed. 2. X + 276 pages, illus. 1939. 12/6 net.

THE first edition of this book was published in 1934 with the purpose in view of providing the research worker in soils with a laboratory manual of methods. In the second edition the subject matter has been completely revised, old methods dropped and newer ones incorporated, with an increase in size of only 40 pages.

The new material deals mainly with the latest developments in mechanical analysis, base exchange, freezing point and hydrogen-ion determination, soil colloids, and methods of determining some of the rarer elements in soils. Like the first edition, the methods are given in such detail that the analyst can carry out the procedures without reference to original sources

The American soil's worker especially interested in so-called quick tests will find little in the book to interest him, but the soil analyst interested in the latest approved methods of soil analysis and their detailed procedure will find the volume helpful. (R C.C.)

AGRONOMIC AFFAIRS

FIRST INTERNATIONAL TOBACCO CONGRESS

A preliminary announcement has appeared of the First International Tobacco Congress to be held at Bremen September 25 to 30, 1939. For further details address the Secretary General, H. Aschenbrenner, at the office of the Congress, 116 Langenstrasse, Bremen, Germany.

THE MINOR ELEMENTS

THE third edition of a "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition", published by the Chilean Nitrate Educational Bureau, is now available.

Comprising 488 pages and containing 4,628 abstracts and references, the volume constitutes another invaluable aid to the investigator. According to a foreword by the publishers, the first edition, compiled by Dr L. G. Willis of the North Carolina Agricultural Experiment Station and published by the Chilean Nitrate Educational Bureau in 1935, contained 1,805 abstracts and references The second edition was published in 1937 and contained 2,766 abstracts and references. The third edition presents some changes in format and general method of presentation.

The abstracts and references are grouped under the different elements, such as aluminum, antimony, arsenic, etc., and the subject index also permits ready reference to articles dealing with any one of the several elements. An author index completes the volume.

THE SPRAGG MEMORIAL LECTURES

DR. LEWIS JOHN STADLER, principal geneticist, Office of Cereal Crops and Diseases, Bureau of Plant Industry, U S Dept. of Agriculture, and associate professor of Field Crops, College of Agriculture, University of Missouri, gave the ninth series of Frank Azor Spragg Memorial Lectures, May 16 to 19, at Michigan State College, East Lansing

These lectures were set up by the Michigan State Board of Agriculture in 1930 as a memorial of the contributions to Michigan agriculture by Frank Azor Spragg, plant breeder at the Michigan Station from 1906 to 1924. Dr. Stadler is a world-renowned authority on the X-ray and ultra-violet radiation of plants for the purpose of changing their genetic constitution. His lecture and four discussion periods centered on the following topics: Cumulative Hybridization, the Physical Analysis of Heredity, the Genetic Effects of X-rays, Some Genetic Experiments with Ultra-Violet Radiation, and "Gene" Mutation.

THE IOWA STATE COLLEGE PRESS

A new publication outlet for manuscripts dealing with science and technology has been provided at Iowa State College, Ames, Iowa, by the recent organization of the Iowa State College Press.

The new press will consider for publication manuscripts, not from Iowa State College alone, but from any source. It will be especi-

ally interested in developing publications in certain subject matter fields in science and technology for which satisfactory publication channels are not elsewhere available. The manufacture and sale of Iowa State College Press publications will be conducted by the Collegiate Press, Inc., also of Ames, a firm which entered the publishing field in 1934 and which has experienced a consistent growth since. Its books have been sold in more than 30 foreign countries as well as throughout the United States.

NEWS ITEMS

DEAN C. ANDERSON has resigned as instructor in agronomy and plant genetics at the University of Minnesota to accept an appointment as agent in corn investigations, U S Dept. of Agriculture, with headquarters at Columbia, Mo.

THE IMPERIAL BUREAU OF PLANT BREEDING AND GENETICS at Cambridge, England, has issued a bulletin on "The Action and Use of Colchicine in the Production of Polyploid Plants", by J L. Fyfe, with a bibliography of 38 references The bulletin is listed at 1s. The Bureau also offers a "Bibliography of Baking Quality Tests", containing titles of papers on this subject published from 1933 to 1938, inclusive, and supplementing earlier bibliographies in this field also published by the Bureau.

ACCORDING TO *Science*, a Soil Science Society of Florida was organized on April 18 with Dr R. V. Allison of the University of Florida, Gainesville, President; Dr Michael Peech of the Citrus Experiment Station at Lake Alfred, Vice-President, Richard A. Carrigan of the Florida Agricultural Experiment Station Gainesville, Secretary-Treasurer; and Henry C Henricksen of Eustis, member of the Executive Committee.

DR. H. H. LOVE, Professor of Plant Breeding at Cornell University, Ithaca, New York, is spending the months of May and June at the Agricultural Experiment Station of the University of Puerto Rico. Dr. Love has been invited by the Director of the Station, Dr J. A. B. Nolla, to advise with the Station staff regarding their research projects. He is to give special attention to the application of methods of statistical analysis to the results already obtained and to advise relative to new types of investigation. Dr. Love has done similar work in Hawaii, China, and several centers in the United States.

THE FOLLOWING persons have been designated to represent the American Society of Agronomy at the Sixth Pacific Science Congress: F. N. Briggs, D. R. Hoagland, W. P. Kelley, and C. F Shaw, from California; W. L. Powers from Oregon; and E. G. Schafer from Washington.

DR. O. S. AAMODT, Head of the Department of Agronomy at Madison, Wisconsin, has been appointed chairman of the Joint Committee on Pasture Improvement in the place of P. V. Cardon who resigned because of increased duties incident to becoming

Assistant Chief of the Bureau of Plant Industry. Dr. Cardon will continue to serve as a member of the committee.

A LIMITED number of copies of three papers dealing with the improvement of naturally cross-pollinated forage crops, presented at the last annual meeting of the Society in Washington, is available. While the supply lasts, a copy may be obtained by addressing the U. S. Regional Pasture Research Laboratory, State College, Pa. The titles and authors of the papers are as follows: "Strain Building", by T. M. Stevenson; "Self and Cross Sterility and Fertility", by S. S. Atwood; and "Inbreeding and the Utilization of Inbred Lines", by W. M. Myers.

REMAINING sets of the PROCEEDINGS of the First International Congress of Soil Science will be sold for $2.50 for the four-volume set, post paid. Volumes 1 and 2 report the proceedings of Commissions I and II, respectively, volume 3 of Commissions III and IV, and volume 4 of Commissions V and VI.

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THE OXIDATION-REDUCTION POTENTIALS OF ALABAMA SOILS AS AFFECTED BY SOIL TYPE, SOIL MOISTURE, CULTIVATION, AND VEGETATION[1]

N. J. VOLK[2]

OXIDATION-REDUCTION potentials of soils have been used by a number of workers during the past five years for interpreting certain soil phenomena associated with plant growth and bacterial action. Bradfield, Batjer, and Oskamp (1)[3] published data in 1934 indicating that a relationship exists between the productiveness of apple trees and the redox potential of the soils in New York State. Sturgis (11) found that reduction was intense in waterlogged rice fields provided active organic matter was present, but the Eh values obtained could not be used to interpret the ability of submerged soil to produce rice. According to Breazeale and McGeorge (2), reduction (especially denitrification) begins when the puddling point has been reached in soils. Results obtained by Burrows and Cordon (3) revealed that different forms of organic matter caused different types of bacterial action and affected the development of different potentials. Remezov (9), working with podzols poor in humus, observed no changes in Eh on standing and concluded that changes in Eh are affected by weather, supply of organic matter, and biological action. Heintze (4) obtained reduction in soils in one to two days time by waterlogging them in the presence of easily decomposable organic matter. Data are presented by Kononova (6) to show that for certain soils the flood system of irrigation caused a fall in Eh and increased denitrification while furrow irrigation caused no such reactions. Smolik (10) found that drainage by means of tile caused a rise in Eh of 90 to 250 millivolts for certain podzols. Herzner (5), in studying the Eh of subsoils, found them to be more or less constant, due, he believed, to the absence of bacteria.

Remezov (8), while investigating the dyanamics of oxidation-reduction potentials, found that as podzols became more swampy the Eh fell. He also found that Eh decreased with depth, that sandy soils

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication February 25, 1939.

[2]Soil Chemist.

[3]Figures in parenthesis refer to "Literature Cited", p. 588.

varied more in Eh during the season than did clays, and that climatic factors caused greater differences in Eh than did cultural practices or vegetation.

In view of the results obtained by some of the above investigators, a project was begun at the Alabama Agricultural Experiment Station in 1936 for the purpose of determining the relation of redox potentials of soils to soil characteristics, fertility, weathering processes, decomposition of organic matter, and plant ecology. The present paper deals with the factors affecting soil Eh and with the magnitude of seasonal fluctuations of the Eh of Alabama soils under different cultural practices.

SELECTION OF SOIL AREAS AND METHOD OF SAMPLING

Since cultural practices might affect the Eh of soils, wherever possible two adjacent areas were selected on a given soil type—one being cultivated and the other being woodland or grassland. In most instances the two areas selected were not over 100 feet apart. These areas were carefully located on 24 different soil types scattered over the northern two-thirds of Alabama, several of which were located in each of the different soil provinces. The soil types selected are given in Table 1 and, as will be noted, they include most of the common agricultural soils of the state.

TABLE 1.—*The arrangement of noncultivated soil types according to the average annual Eh value of the 0- to 8-inch depth.*

Soil	Eh at pH 6.0	Soil	Eh at pH 6.0	Soil	Eh at pH 6.0
Durham fine sandy loam	496	Cecil sandy loam	521	Waynesboro clay loam	538
Wehadkee clay	501	Hanceville fine sandy loam	523	Congaree clay loam	539
Norfolk sandy loam	511	Leaf fine sandy loam	528	Eutaw clay	540
Decatur clay loam	512	Amite clay loam	531	Atkins clay	541
Colbert clay	514	Kalmia fine sandy loam	535	Catalpa clay	546
Houston clay	515	Oktibbeha clay	536	Davidson clay loam	549
Huntington clay loam	519	Holly clay	536	Vaiden clay loam	550
Pope clay	520	Susquehanna sandy loam	537	Vaiden clay loam (buckshot)	552

In order to obtain representative samples of these soils every 2 weeks throughout the year, five holes were bored at each location at each sampling date. Care was taken not to contaminate the soils from the 0- to 8-inch, the 8- to 16- inch, and the 16- to 24-inch depths with each other. Each composite of five borings was quickly and thoroughly mixed and a portion of it was immediately placed in a 60-cc bottle containing 30 cc of water saturated with nitrogen and cooled to about 35° F. Enough soil was added to push the water just into the neck of the bottle, as this insured a uniform size of sample and at the same time excluded all of the air. The bottle was then corked with a paraffined cork and replaced in a cooler to prevent reduction (12). Another portion of the soil was placed in an airtight container and its moisture content determined later.

METHODS OF ANALYSES

The analyses for redox potential and pH were made simultaneously within 72 to 96 hours after sampling according to the methods described in a previous paper (12). In addition to Eh and pH, the moisture content of the soil at sampling time was determined.

FACTORS AFFECTING SOIL EH

SOIL TYPE

Since Eh is dependent on the kinds of ions in solution, their states of oxidation, and their relative concentrations, it appeared likely that different soil types under similar cultural practices might have different Eh values, and this proved to be the case. In order to avoid man-induced complications existing in cultivated soils, it is best to consider only virgin areas when attempting to study any relation that may exist between soil Eh and soil type. The virgin soils studied in Alabama have been arranged according to their average annual Eh values as shown in Tables 1, 2, and 3. When the results are examined, differences are found in Eh values of soils which are difficult to explain. For example, Atkins clay, Catalpa clay, and Holly clay, which are more or less swampy soils known to be in a waterlogged state for long periods of time, were found to be considerably higher in Eh than several soils known to be well-oxidized, such as Decatur clay loam and Cecil sandy loam.

TABLE 2.—*The arrangement of noncultivated soil types according to the average annual Eh of the 8- to 16-inch depth.*

Soil	Eh at ph 6.0	Soil	Eh at pH 6.0	Soil	Eh at pH 6.0
Wehadkee clay	297	Amite clay loam	528	Holly clay	540
Houston clay	505	Oktibbeha clay	530	Leaf fine sandy loam	541
Colbert clay	510	Waynesboro clay loam	532	Eutaw clay	542
Decatur clay loam	513	Norfolk sandy loam	532	Catalpa clay	549
Huntington clay loam	517	Susquehanna sandy loam	533	Davidson clay loam	551
Durham fine sandy loam	519	Hanceville fine sandy loam	533	Congaree clay loam	552
Cecil sandy loam	521	Vaiden clay loam (buckshot)	535	Atkins clay	552
Pope clay	521	Vaiden clay loam	538	Kalmia fine sandy loam	553

Because of these results it is considered inadvisable to compare one soil type with another as regards Eh and to interpret from that comparison a difference in the states of oxidation. Peech and Boynton (7) have shown that poorly drained soils often contain MnO_2 concretions. It is possible that such a condition existed in Atkins clay, Catalpa clay, and Holly clay and that stirring of those soils during analysis allowed the MnO_2 to oxidize certain compounds existing in those soils in a reduced state. To the author, however, it seemed more reasonable to believe that the Eh of those particular soils was more dependent on

the kinds and ratios of materials in solution than upon the states of oxidation of those materials. The above statement, however, does not mean that reduction of the compounds existing in a given soil would not cause a drop in potential.

TABLE 3.—*The arrangement of noncultivated soil types according to the average annual Eh of the 16- to 24-inch depth*

Soil	Eh at pH 6.0	Soil	Eh at pH 6.0	Soil	Eh at pH 6.0
Wehadkee clay	315	Susquehanna sandy loam	520	Leaf fine sandy loam	534
Cecil sandy loam	479	Pope clay	520	Waynesboro clay loam	536
Colbert clay	483	Vaiden clay loam	523	Catalpa clay	539
Houston clay	503	Norfolk sandy loam	524	Holly clay	541
Amite clay loam	504	Hanceville fine sandy loam	525	Atkins clay	545
Durham fine sandy loam	509	Decatur clay loam	525	Kalmia fine sandy loam	550
Huntington clay loam	515	Vaiden clay loam (buckshot)	527	Davidson clay loam	552
Oktibbeha clay	519	Eutaw clay	534	Congaree clay loam	555

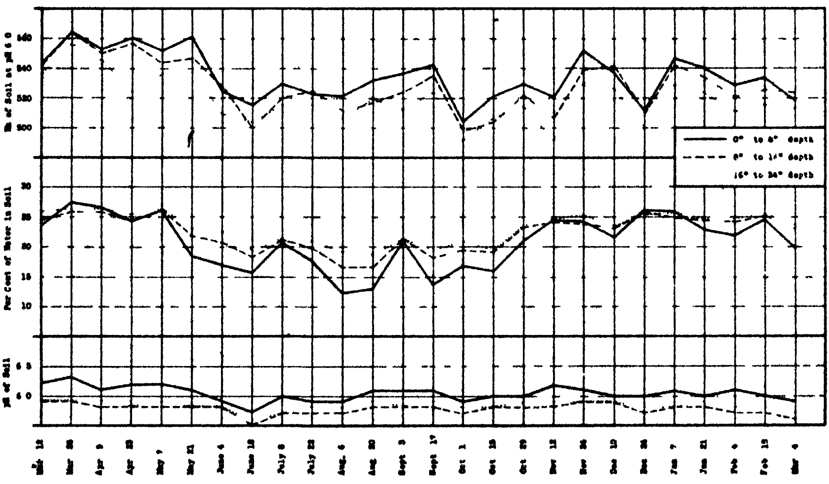

FIG. 1.—Seasonal fluctuations in Eh, pH, and soil moisture at three depths for the average of 40 arable soils of Alabama.

CULTIVATION VS. CONTINUOUS VEGETATIVE COVER

There is ample evidence to show that the decomposition of organic matter under waterlogged conditions usually results in a marked lowering of the Eh even though different kinds of organic matter produce different by-products during decomposition and thus affect the potential differently (3). Since the cultivation of soils causes a depletion of organic matter, it is reasonable to expect that cultivated soils will have higher potentials than corresponding soils under con-

tinuous vegetation (grass and trees). A study of the data in Table 4 shows that there is a difference in the Eh of the surface of cultivated and noncultivated soils in many cases, but that no consistent differ-

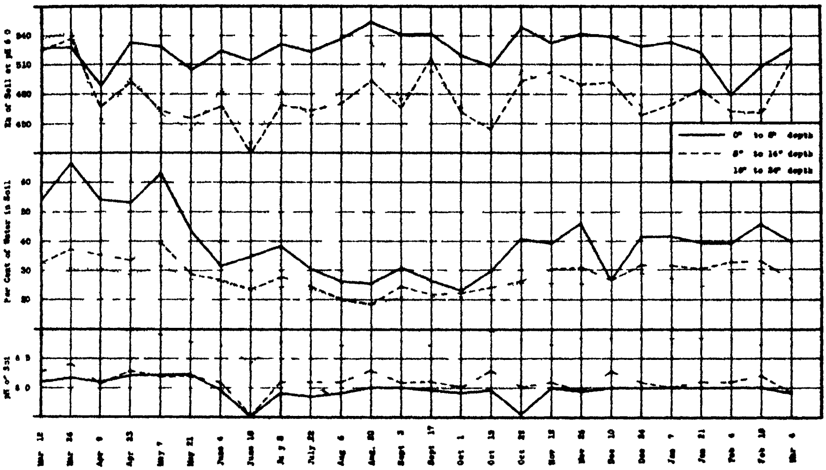

FIG. 2 Seasonal fluctuations in Eh, pH and soil moisture at three depths for the average of four swampy soils of Alabama Wehadkee clay Holly clay, Pope clay, and Atkins clay

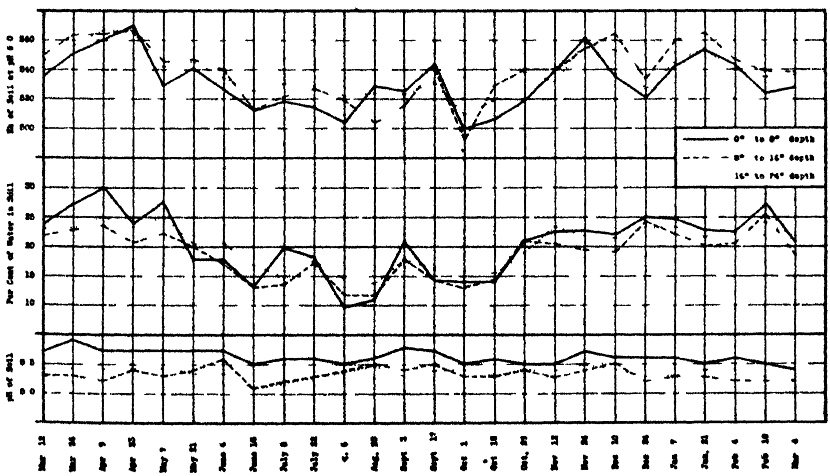

FIG 3 —Seasonal fluctuations in Eh, pH, and soil moisture for Congaree clay loam, Huntington clay loam, Waynesboro clay loam, Leaf fine sandy loam, and Kalmia fine sandy loam (woodland soils)

ence exists in the subsoils. The greatest differences were found to occur in the alkaline Black Belt soils where grassland showed an average of 44 millivolts lower than cultivated land in the surface 0- to 8-inches

TABLE 4.—*The average annual Eh of cultivated soils as compared with woodland or grassland soils.*

Soil type	Eh of soils in millivolts at pH 6.0					
	0–8 in. depth		8–16 in. depth		16–24 in. depth	
	Cultivated	Woodland and grassland	Cultivated	Woodland and grassland	Cultivated	Woodland and grassland
Piedmont						
Cecil sandy loam	519	521	518	521	483	479
Davidson clay loam	548	549	553	551	547	552
Congaree clay loam	555	539	571	552	571	555
Durham fine sandy loam	542	496	521	519	491	509
Average	541	526	541	536	523	524
Limestone Valley						
Decatur clay loam	543	512	536	513	525	525
Huntington clay loam	543	519	544	517	537	515
Colbert clay	539	514	527	510	501	483
Average	542	515	536	513	521	508
Appalachian						
Hanceville fine sandy loam	525	523	533	533	529	525
Waynesboro clay loam	530	538	540	532	539	536
Average	528	531	537	533	534	531
Acid Black Belt						
Vaiden clay loam (buckshot)	518	552	509	535	519	527
Eutaw clay	532	540	520	542	513	534
Vaiden clay loam	576	550	552	538	542	523
Oktibbeha clay	546	536	526	530	520	519
Average	543	545	527	536	524	526
Alkaline Black Belt						
Catalpa clay	586	546	584	549	573	539
Houston clay	564	515	530	505	529	503
Average	575	531	557	527	551	521
Coastal Plain						
Leaf fine sandy loam	549	528	546	541	529	534
Kalmia fine sandy loam	497	535	506	553	516	550
Amite clay loam	538	531	522	528	506	504
Susquehanna sandy loam	525	537	498	533	494	520
Norfolk sandy loam	543	511	549	532	541	524
Average	530	528	524	537	517	526
Average for all soils	541	530	534	532	525	523

and about 30 millivolts lower in the 8- to 16- and 16- to 24-inch depths. These differences, however, appear to be of insufficient magnitude to be considered factors in affecting plant growth from the standpoint of potential alone.

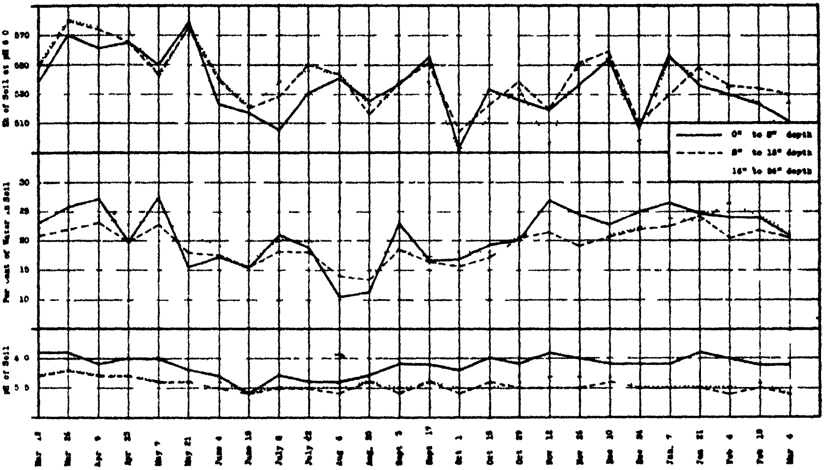

FIG 4 – Seasonal fluctuations in Eh, pH, and soil moisture for Congaree clay loam, Huntington clay loam, Waynesboro clay loam, Leaf fine sandy loam, and Kalmia fine sandy loam (cultivated soils)

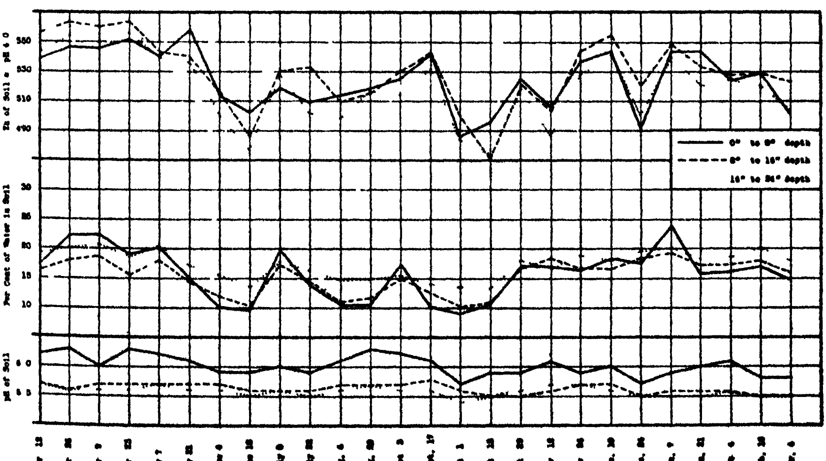

FIG. 5.—Seasonal fluctuations in Eh, pH, and soil moisture for Cecil sandy loam, Davidson clay loam, Decatur clay loam, Hanceville fine sandy loam, Amite clay loam, and Norfolk sandy loam (woodland soils).

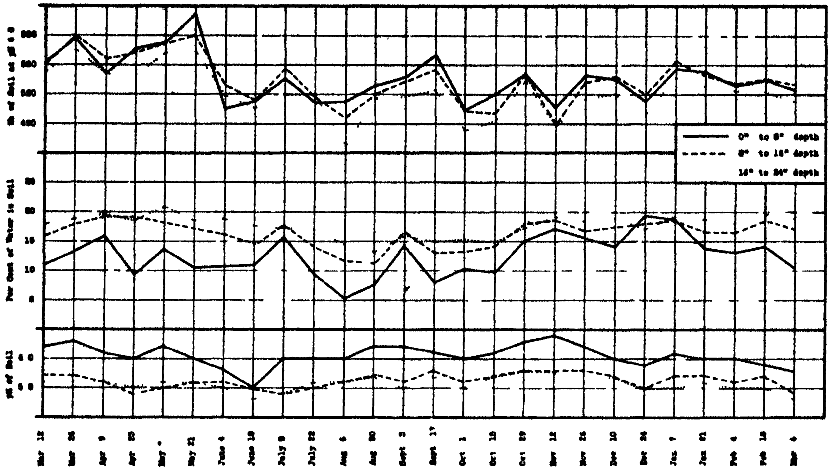

FIG 6.—Seasonal fluctuations in Eh, pH, and soil moisture for Cecil sandy loam, Davidson clay loam, Decatur clay loam, Hanceville fine sandy loam, Amite clay loam, and Norfolk sandy loam (cultivated soils)

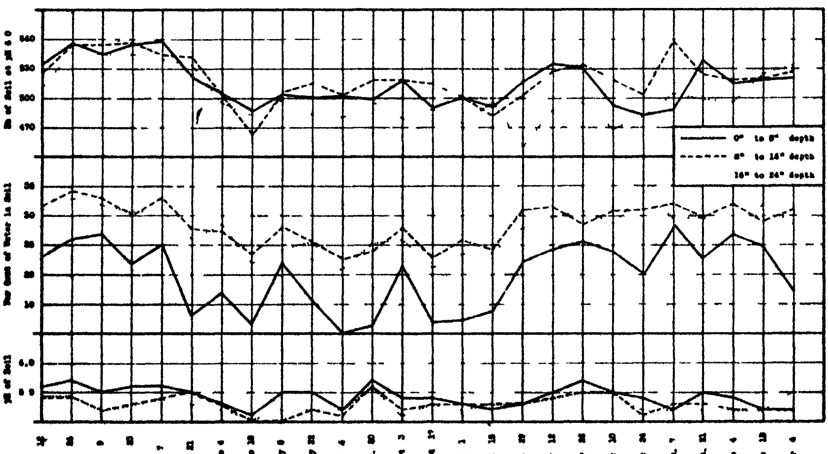

FIG. 7.—Seasonal fluctuations in Eh, pH, and soil moisture for Durham fine sandy loam, Colbert clay, and Susquehanna sandy loam (woodland soils).

SOIL MOISTURE

Previous to this study, it was generally believed that an increase in soil moisture would cause a lowering of soil Eh as a result of increased bacterial action. Results (Fig. 1) obtained at the Alabama Experiment Station, however, reveal that, while there is a definite relation between the amount of moisture in the soil and the resultant Eh, the relationship is the reverse of what might be expected. As the soil

moisture increases the Eh increases, and *vice versa*. A possible explanation of this may be as follows: The rain contains a good supply of oxygen and as it passes into the soil it oxidizes existing reduced compounds and causes a rise in the Eh of the soil. Later, the bacteria get into full action and deplete the soil of oxygen and it remains so until bacterial action subsides due to a lack of moisture or organic matter. Such a cycle in the soil could easily account for the results given in

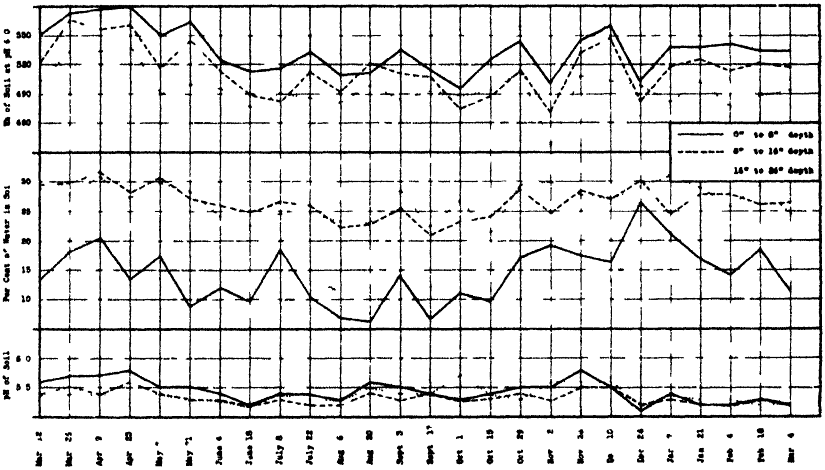

FIG. 8—Seasonal fluctuations in Eh, pH, and soil moisture for Durham fine sandy loam, Colbert clay, and Susquehanna sandy loam (cultivated soils).

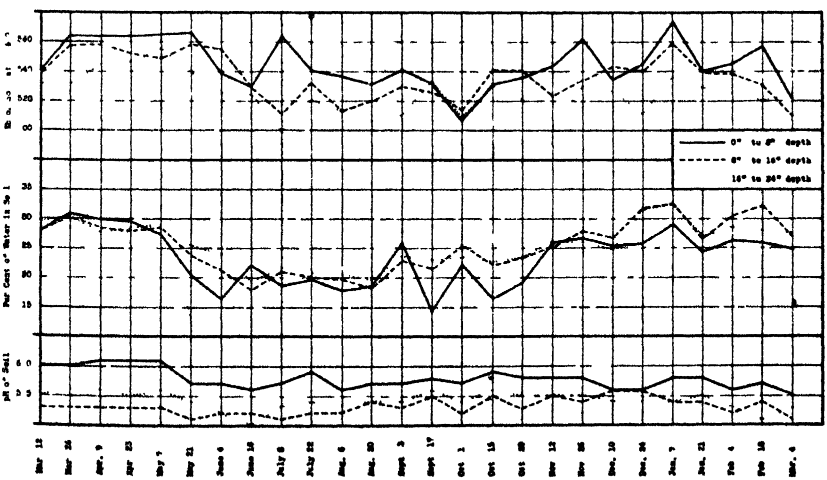

FIG. 9—Seasonal fluctuations in Eh, pH, and soil moisture for Vaiden clay loam (buckshot), Vaiden clay loam, Eutaw clay, and Oktibbeha clay (woodland soils).

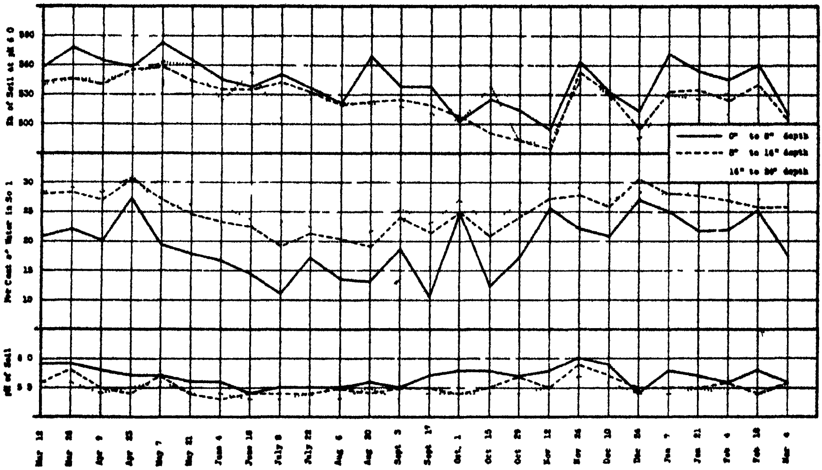

FIG 10.—Seasonal fluctuations in Eh, pH, and soil moisture for Vaiden clay loam (buckshot), Vaiden clay loam, Eutaw clay, and Oktibbeha clay (cultivated soils).

Figs. 1 to 12, inclusive. The above theory is further supported by the fact that the Eh of a stagnant mudhole proved to be lower before a rain than after.

A study of Figs. 1 to 12, inclusive, shows that during the wet months (late fall, winter, and spring) the potential is the highest, while during the drier summer months the potential is lower. The above trend did not hold consistently in the case of swamp soils which

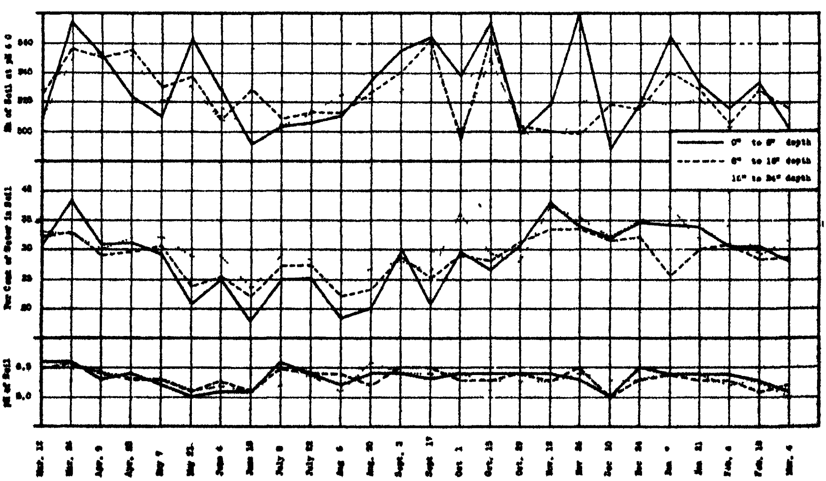

FIG. 11.—Seasonal fluctuations in Eh, pH, and soil moisture for Catalpa clay and Houston clay (woodland soils).

remained in a waterlogged state the greater part of the year (Fig. 2). The peculiar behavior of these swamp soils depends on a number of factors, such as the amount of material carried into them by flood water, the degree to which they dry out during certain seasons, the amount of food available to bacteria in the stagnant water, and the temperature of the water.

Even though seasonal fluctuations in Eh did occur for the arable soils, the fluctuations were of such small magnitudes (around 60 millivolts as a maximum as measured by the author's method) that it hardly seems possible that they could affect plant growth to any degree.

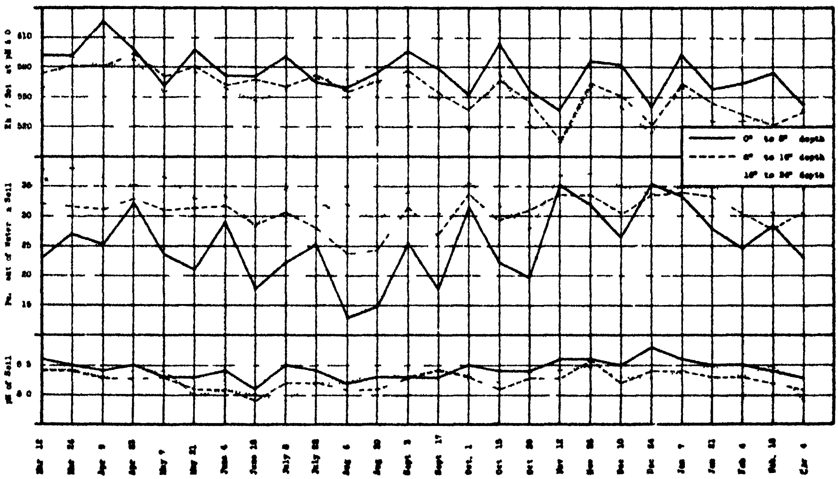

FIG. 12.—Seasonal fluctuations in Eh, pH, and soil moisture for Catalpa clay and Houston clay (cultivated soils).

DISCUSSION

The Eh of a soil is the intensity factor in oxidation and reduction just as pH is the intensity factor in soil acidity—the pH is dependent on the hydrogen-ion concentration, whereas the Eh is dependent on the relative concentrations and states of oxidation of all ions present and thus must be calculated to a common pH value for comparative purposes. Different ions in the same state of oxidation have different Eh values and identical ions in different states of oxidation have different Eh values. Thus it is believed that it is possible for some ions existing in an oxidized state in soils to have lower Eh values than other ions existing in soils in a reduced state. Therefore, when the Eh of any given soil is obtained it is doubtful whether or not its state of oxidation or reduction is known since the potential depends not only on the ratio of oxidized to reduced phases of the ions present but also on the kinds and relative amounts of ions present. Also, if a particular soil changes in Eh during the season, one cannot definitely say there is a change in the state of oxidation because the factor or factors

causing the change in Eh may have brought into solution or thrown out of solution ions of different chemical composition and different Eh values without altering the state of oxidation of the soil as a whole.

Considering the points set forth above, it is believed quite possible that the changes in Eh occurring in arable Alabama soils are of little consequence as regards plant growth. A study dealing with this phase of the problem is in progress and the results will be reported at a later date.

SUMMARY

This study was undertaken for the purpose of determining some of the factors affecting soil Eh and to determine the magnitude of the fluctuations in Eh for different Alabama soils under different cultural practices. The results obtained are as follows:

1. Cultivated soils generally have a slightly higher Eh (about 10 millivolts) in the 0- to 8-inch depth than do woodland and grassland soils, but this difference is not carried into the subsoil as a rule.
2. Differences in Eh due to soil types do exist, but the differences are small for arable soils, seldom being over 50 millivolts. Data obtained indicate that these differences are often due to variations in soil material rather than to differences in states of oxidation—swampy soils frequently have higher Eh values than do well-aerated upland soils.
3. Increases in moisture in arable soils caused increases in Eh, and *vice versa*. This condition, it is believed, was brought about by oxygen being carried into the soil by rainwater which caused reduced compounds to become oxidized, and later the increased moisture caused increased bacterial action which resulted in a consumption of the oxygen and a lowering of the potential.
4. The seasonal variations in Eh for any arable soil in Alabama seldom exceed 60 millivolts.
5. It appears that Eh determinations do not reveal whether or not an arable soil is in an oxidized or reduced state since the Eh is dependent not only on the ratio of the oxidized to the reduced phases of the ions present but also on the kinds and relative amounts of the ions present.

LITERATURE CITED

1. BRADFIELD, R., BATJER, L. P., and OSKAMP, J. Soils in relation to fruit growing in New York: Part IV. The significance of oxidation-reduction potentials in evaluating soils for orchard purposes. Cornell Univ. Agr. Exp. Sta. Bul. 592. 1934.
2. BREAZEALE, J. F., and MCGEORGE, W. T. Studies on soil structure: Some nitrogen transformations in puddled soils. Ariz. Agr. Exp. Sta. Tech. Bul. 69. 1937.
3. BURROWS, W., and CORDON, T. C. The influence of the decomposition of organic matter on the oxidation-reduction potentials of soils. Soil Sci., 42: 1–10. 1936.
4. HEINTZE, S. G. The use of the glass electrode in soil reaction and oxidation-reduction potential measurements. Jour Agr. Sci., 24:28–41. 1934.
5. HERZNER, R. A. The physical chemistry of cultivated soils: IV. Chemical energy in surface soil and subsoil. Z. Pflanzenernahr Dungung u. Bodenk, 18 A:249–64. 1930.
6. KONONOVA, M. Oxidation-reduction potentials as a method of characterizing conditions of soil under various methods of irrigation. Pedology (U. S. S. R.), 27:365–376. 1932.

7. PEECH, M., and BOYNTON, D. Soils in relation to fruit growing in New York: Part X. Susceptibility of various New York orchard soils to reduction upon waterlogging. Cornell Univ. Agr. Exp. Sta. Bul. 667. 1937.
8. REMEZOV, N. P. The dyanamics of oxidation-reduction potentials in podzol soils. Trans. Sci. Inst. Fert. (Moscow), 77:55-63. 1930.
9. ————. Dyanamics of the oxidation-reduction potential in podzolized soils. Proc. 2nd Intern. Congr. Soil Sci. (Leningrad 1930), 2:212–26. 1933.
10. SMOLIK, L. Reduction potentials in drained and undrained soils. Proc. Intern. Soc. Soil Sci., 12, No. 1. 1937.
11. STURGIS, M. B. Changes in the oxidation-reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. La. Agr. Exp. Sta. Bul. 271. 1936.
12. VOLK, N. J. The determination of redox potentials of soils. Jour. Amer Soc. Agron., 31:344 351. 1939.

THE LATERAL DISTRIBUTION OF POTASSIUM IN AN ORCHARD SOIL[1]

J. H. GOURLEY AND IRVIN W. WANDER[2]

A PREVIOUS report (1)[3] has shown that potassium moves downward slowly in Wooster silt loam soil. Since fruit trees root deeply (from 5 to 6 feet) in this soil, the problem arose as to what method could be employed to supply tree roots with available potassium in case it became necessary or desirable to apply this element. Plainly, a surface application in either a sod or tilled orchard on this soil type would reach the mass of absorbing roots rather slowly, if at all.

In order to test experimentally a method of "deep" application, a set of holes was bored beneath certain trees and a potash fertilizer was introduced in orchard J, plat 7. The orchard used and the procedure were as follows:

An orchard of apple trees was planted in 1922, consisting of Baldwin and Stayman Winesap varieties. Cultivation with cover crops was followed as a cultural system for a few years and then the land was seeded to a nonlegume cover (mostly timothy and blue-grass). Incidentally, this was for the purpose of reducing the naturally occurring nitrate supply and thus bring about an earlier response to nitrogen-carrying fertilizers. One row of 19 trees has been treated with muriate or sulfate of potash together with nitrate of soda since 1928. But, as shown previously, the downward translocation of the potassium has been slow.

In 1935 a soil "plugging" test was started and 16 holes were bored to a depth of 18 inches beneath 10 of the 19 trees in the row. A geometric design was used and mapped so that any hole could be readily located at any time in the future. Thus, eight holes were bored with a king soil tube in a 12-foot circle from the base of the tree and another eight holes were bored in a 9-foot circle alternating with the holes in the 12-foot circle. All the holes were beneath the branches of the trees. The following year 16 holes were again made just outside the periphery of the branches for the fertilizer treatment, but only those treated in 1935 are considered here.

Sixty grams of a potash salt were mixed with approximately two-thirds of the soil removed and this mixture was inserted into the lower 12 inches of each hole (6 inches to 18 inches).

Two or three questions arise as to the ultimate disposition of the exchangeable potassium, whether or not it distributes downward only, laterally also, or is largely immobile. Furthermore, what is the effect of this concentration of salt upon fibrous roots already in close proximity to the holes, do new ones develop in the adjacent soil, and is there an uptake of K into the tree? The first of these questions is here principally considered.

In order to determine whether there has been any movement of the K in a period of three years, samples were taken for quick tests (2) between July 10 and August 16, 1938. A pit was dug 3 feet wide, 4 feet long, and 3 feet deep along the

[1]Contribution from the Department of Horticulture, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication February 25, 1939.
[2]Head of Department and Assistant Horticulturist, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 597.

side of the cores into which had been placed the potash and soil mixtures (trees 6, Fig 1)

Samples were taken 1 inch wide, 1 inch thick, and 6 inches long on either side of the core at 1 inch intervals laterally to a distance of 10 inches In most cases

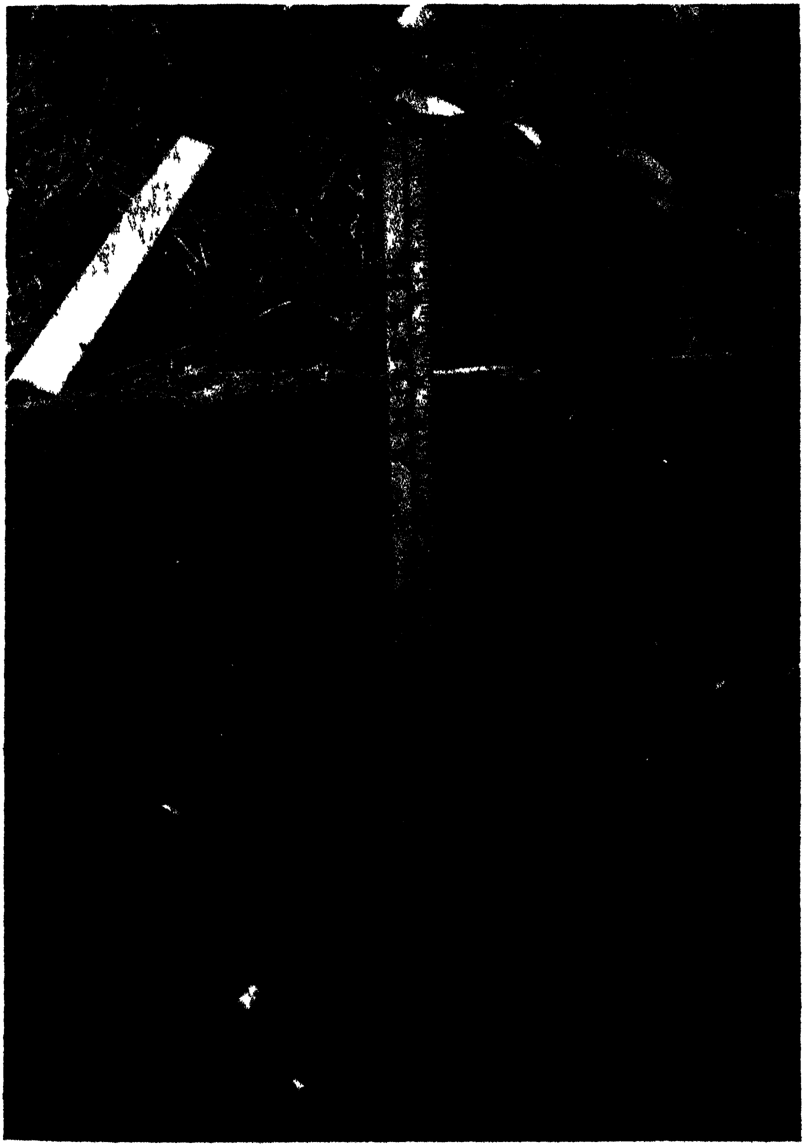

FIG 1 —To the right of yardstick is shown the core of soil containing the potash salt

the depth of the samples was limited to 24 inches because of shale encountered. Thus, in all cases except one (tree 19, Fig. 6), a total of 84 samples were taken per core. In this latter case it was necessary to go further out from the side of the core in order to determine the periphery of the zone of very high available potassium.[4]

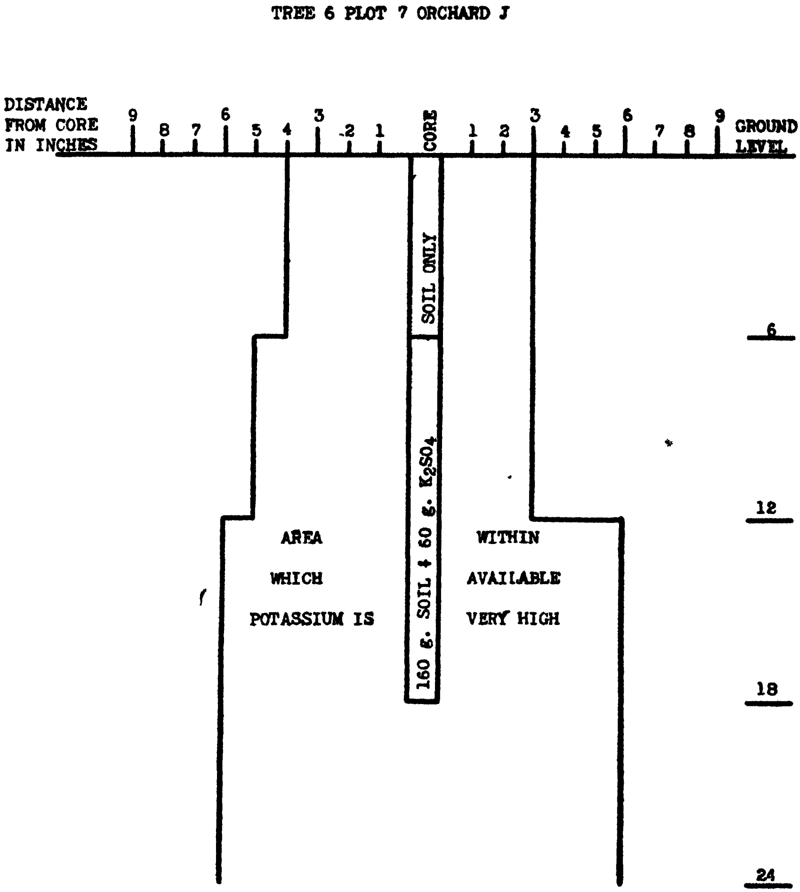

FIG. 2 —Diagram showing the lateral distribution of exchangeable potassium from core shown in center of figure.

RESULTS

The first tree studied (tree 6) showed that not only had there been lateral movement of the K but that the soil water presumably had carried it upward to the surface and also laterally to a distance of

[4]The quick test used was developed at Purdue University and is known as the "Thornton test." In general, the test for potassium consists of thoroughly mixing 1 teaspoon of air-dried, screened soil with a solution of sodium cobaltinitrite in acetic acid. The amount of potassium is then estimated by adding isopropyl alcohol to an aliquot of the filtrate and judging the turbidity formed by the precipitate. This method was found to give reproducable results when used on these particular soil samples.

3 inches on one side to 4 inches on the other so that it tested "very high" in that 6-inch surface zone where no K had been inserted (Fig. 2). In the 6- to 12-inch zone the soil tested very high to 3 inches on one side and 5 inches on the other, from 12 to 18 inches the distribution had widened in a radius of 6 inches. It had also penetrated to a depth of at least 24 inches and 6 inches on either side of the core or axis. In other words, these boundaries represent the limits to which the bulk of available K has penetrated since the transition from "very high" to "low" or "very low" does not extend more than 2 or 3 inches beyond. Thus, the general contour of the movement was roughly in the shape of a flask or bottle.

Cores selected at random under trees 10, 11, 14, and 19 were likewise studied. The picture varies somewhat from tree to tree, probably due to variations in soil texture and slope of strata, but in the main confirms the findings of the first one, namely, that there is a decided lateral movement of this element in the soil.

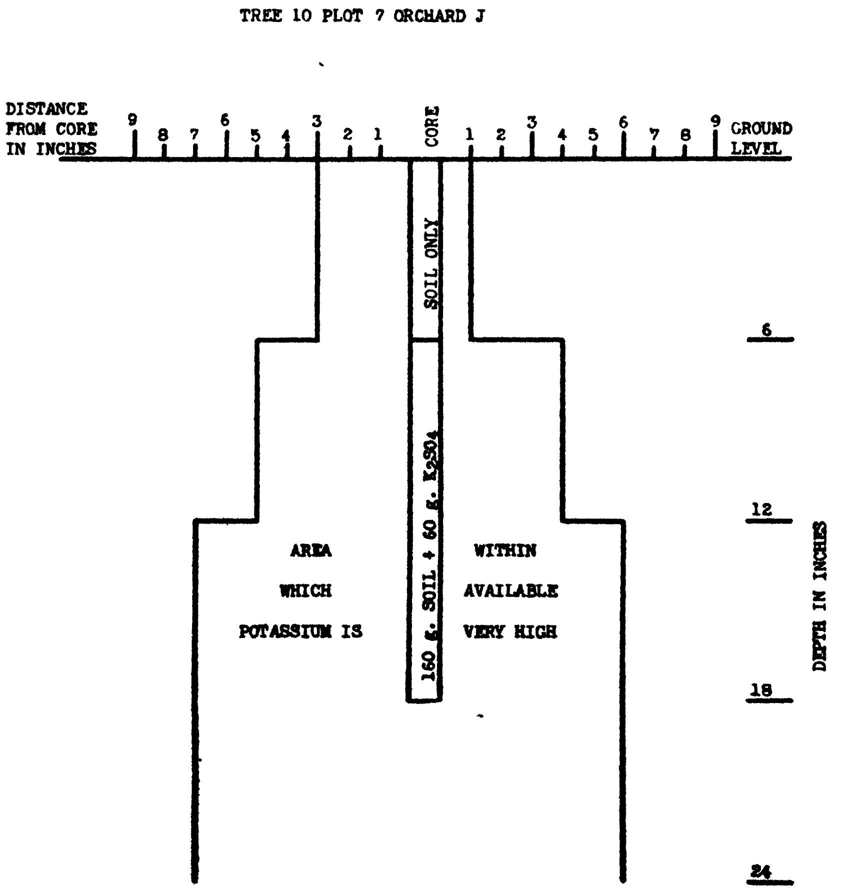

FIG. 3.—Diagram of tree 10 showing distribution of potassium.

Tree 10 shows a pattern quite similar to that found under tree 6. In both cases sulfate of potash was used (Fig. 3).

Tree 11, where the muriate form of the salt was used, shows a reversal in pattern in that the widest distribution is at the upper 6 inches where the core was filled with soil only. At the base the radius from the core is 5 and 6 inches, respectively (Fig. 4). That this difference is due to the form of salt used is not suggested but is worthy of note.

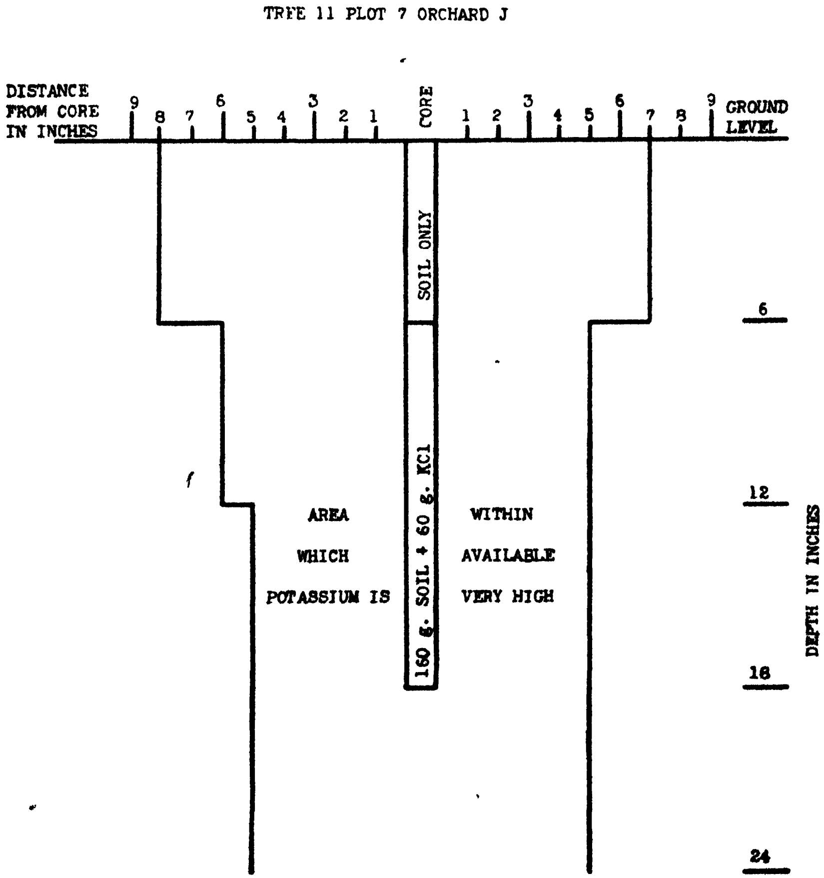

FIG. 4.—Diagram of tree 11 showing distribution of potassium. Note the difference in shape of the outline compared to the preceding figures.

The samples taken beneath tree 14 show a more irregular outline with a wider distribution on one side than the other below a level of 12 inches (Fig. 5).

The core selected beneath tree 19 showed a still greater variation from the others. The movement for the entire depth is nearly unilateral but involves a wide area, being 16 inches in the upper level (Fig. 6).

While no quantitative determinations were made, it was observed throughout these excavations that live, fibrous roots were present within the zone of "very high" potassium. This would mean that a tree deficient in K should obtain ample supplies from the soil, if some such technic as that here described were used.

Volk (3) and Volk (4) found that the alternate wetting and drying of a mixture of a soluble potassium salt and certain soils at 70° C

TREE 14 PLOT 7 ORCHARD J

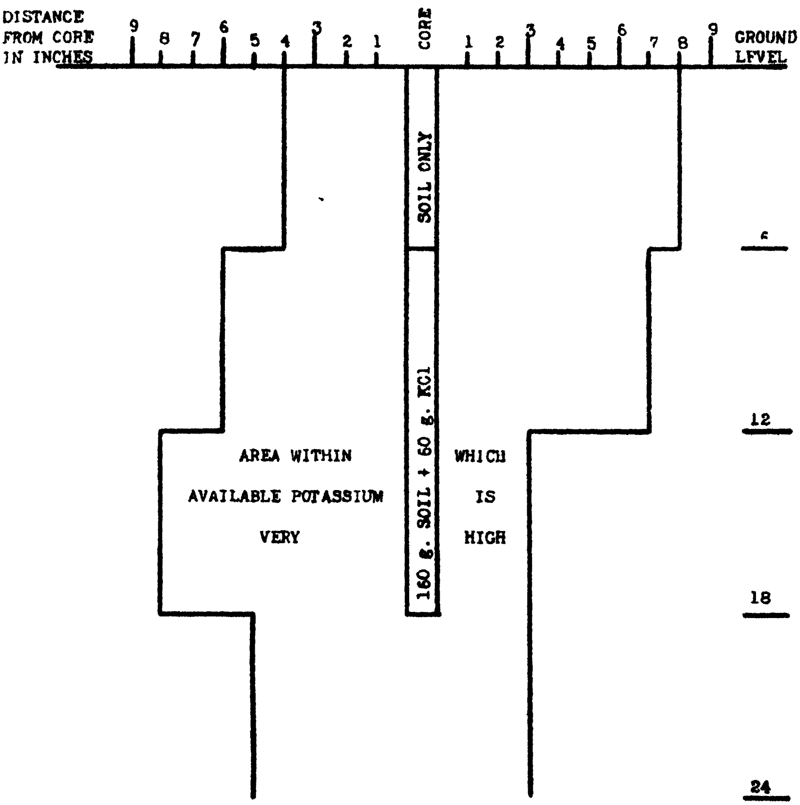

FIG. 5.—Diagram of tree 14 showing distribution of potassium

caused a large amount of the potassium to be fixed in a difficultly available form. Thus, potash applied on the surface or just slightly beneath the surface of a soil will fail to move downward to any appreciable extent since this zone would be subject to alternate wetting and drying. But, they also found that when soluble potassium is in contact with soil under continuous moist conditions, such as would be found at the lower soil depths, fixation is very slow.

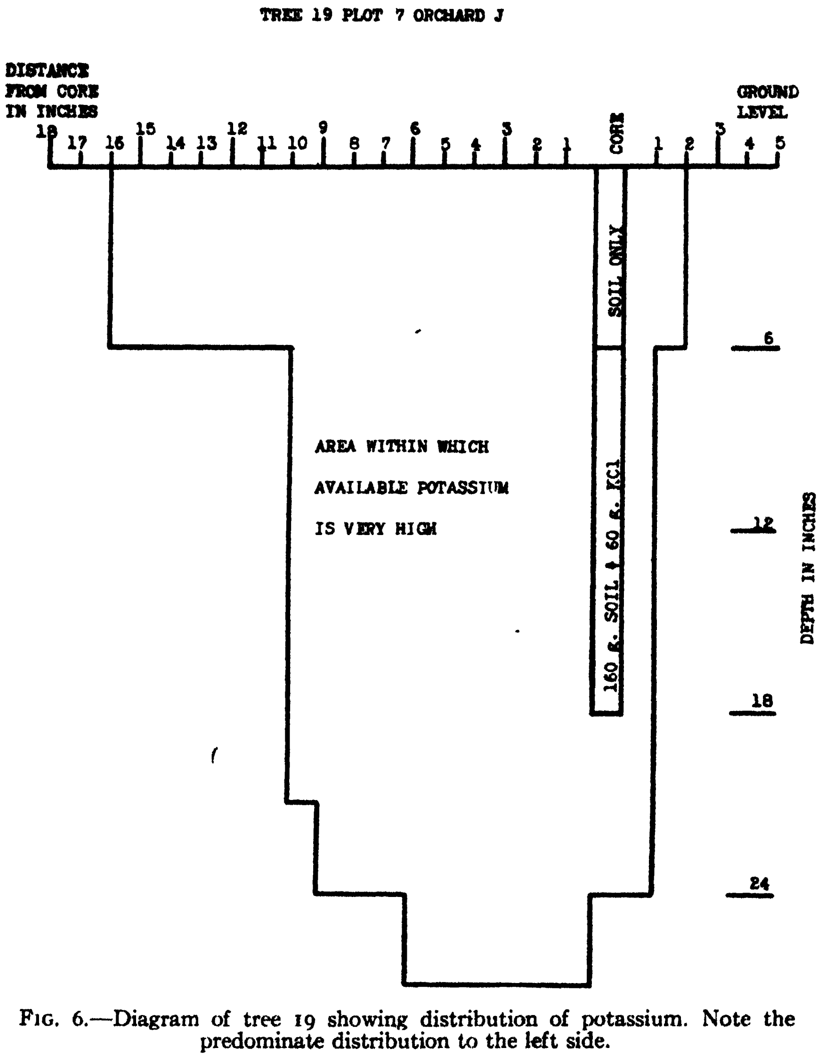

FIG. 6.—Diagram of tree 19 showing distribution of potassium. Note the predominate distribution to the left side.

Trüog and Jones (5) explain the fixation of potassium in their conclusions by stating that, "when the exchange material is saturated with potassium and the material is then dried, which is supposed to bring the layers or plates of the crystal lattice together, the presence of the potassium offers such strong attraction as to prevent reexpansion of the crystal lattice and thus reentrance of water and opening up of the crystal lattice, causing the potassium to become trapped in non-exchangeable form."

Furthermore, they state that the, "introduction of organic matter, which supplies organic base exchange material, should also be helpful, since entrance of potassium in the organic exchange material renders

the potassium safe from fixation in non-exchangeable form for the time being."

These suggestions and conclusions fit closely the observations which have been reported in this paper as well as previously (1), showing the large amount of exchangeable potassium found under mulched apple trees with straw and similar organic materials.

DISCUSSION AND SUMMARY

This investigation of potassium movement in the soil is of interest to horticulturists from several standpoints, particularly to those who have to deal with a deficiency of this element in orchards.

The first objective was that of determining whether there would be a lateral movement of sufficient extent to make potassium available to a mass of tree roots without injury to the new ones which develop in such a zone.

It is interesting to note that these areas represent from 1.4 to 2.2 cubic feet of soil per core in which the available K has become very high within a period of 3 years. Assuming all areas affected by the cores to be similar under the same tree, approximately 22.4 to 35.2 cubic feet of soil per tree would be affected by the 16 cores per tree. This means that, under an experimental test, from 1.6 to 2.5 per cent of the total soil 13 feet away from the tree trunk and 2 feet deep has been increased from a low or very low available K content to a very high available content.

That roots would develop in this area and not be injured is worthy of note, although quantitative determinations of the root population was not attempted.

From a practical standpoint, it would mean that potash fertilizers could be dropped behind a deep tillage tool, such as a Killifer disk or coulter, to a depth of 16 to 18 inches. This would be within the active absorbing zone of the tree roots in most eastern orchard soils and also below the zone in which potassium is fixed by alternate wetting and drying. Its lateral movement should then be ample for supplying the needs of the tree.

LITERATURE CITED

1. Wander, I. W., and Gourley, J. H. Available potassium in orchard soils as affected by a heavy straw mulch. Jour. Amer. Soc Agron., 3:438-446. 1938.
2. Thornton, S. F., Conner, S. D., and Fraser, R. R. The use of rapid chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Univ. Agr. Exp. Sta. Circ. 204. 1936.
3. Volk, N. J. The fixation of potash in difficultly available form in soils. Soil Sci., 37:267-287. 1934.
4. Volk, G. W. The nature of potash fixation in soils. Soil Sci., 45:263-276. 1938.
5. Truog, Emil, and Jones, R. J. Fate of soluble potash applied to soils. Ind. and Eng. Chem., 30:882-885. 1938.

GEOGRAPHICAL LOCATION AND SOIL ORGANIC MATTER[1]

JACKSON B. HESTER AND F. A. SHELTON[2]

THE soil is a complicated natural body, the chemical elements and compounds of which are influenced by climatic conditions (7, 8, 9).[3] The organic components of the soil are influenced by associated vegetation but are affected mostly by the two chief components of climate, namely, rainfall and temperature. The reaction (pH) of the soil and associated conditions influence the type and quantity of vegetation (5) upon the soil; therefore, the organic matter content is obviously indirectly influenced by the parent geological material from which the soil is built.

The fertility of an economic soil is largely determined by the organic matter content, due to the fact that the organic matter contains the soil nitrogen, etc., and also exhibits various other properties. Then, the destruction of the organic matter to liberate nitrogen, etc., is essential in order to realize its great value in producing crops. Again, the chief components of climate, temperature and rainfall, are important factors.

It was pointed out in a previous publication (4) that comparable data for organic matter should include only soils of a given texture and drainage. In studying the fertility factors of soil on which tomatoes or tomato plants are grown the authors have had a chance to analyze a large group of A_p soil samples[4] from various parts of the United States and Canada for the organic matter content, pH value, and various nutrient elements. These data have been assimilated according to certain textural relation and are given in this discussion. Fig. 1 shows the geographical distribution and number of samples, the mean annual temperature and rainfall, and the texture of the soil of the given sections.

VARIATION OF ORGANIC MATTER CONTENT IN SOIL IN A LONGITUDINAL DIRECTION

The predominating soil types on which tomatoes are grown in the three sections, namely, Colborne, Canada (2, 11); Burlington County, New Jersey (1, 7); and Tifton, Georgia (9), are the well-drained sandy loams. The mean annual temperature of these three sections varies from approximately 44° F at Colborne, Canada, to 52° F at Moorestown, New Jersey to 69° F at Tifton, Georgia, or an approximate variation of 25 degrees. The mean annual rainfall decreases from approximately 48 inches at Tifton to 45 inches in New Jersey to 33 inches in the Colborne section. The organic matter content of the well-drained sandy loams, as shown in Table 1, is between 2.0

[1]Contribution from the Department of Agricultural Research, Campbell Soup Company, Riverton, New Jersey. Received for publication March 10, 1939.

[2]Soil Technologist and Assistant, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 603.

[4]Samples were collected by the field representatives in each section. Only the A_p horizon from tomato-producing soils is considered. The color and texture were classified in the laboratory by the authors on dry samples.

and 3.9% for 71% of the soils around Colborne, whereas, 59 and 69% of the soils in Burlington County and around Tifton, respectively, were in the range of 1.0 to 1.9%. In other words, for an increase of 25 degrees in temperature and 15 inches of rainfall the organic matter content in the soil dropped 1.2%. Thus, the mean organic matter content of the Canadian soils was 2.86% and of the Georgia soils

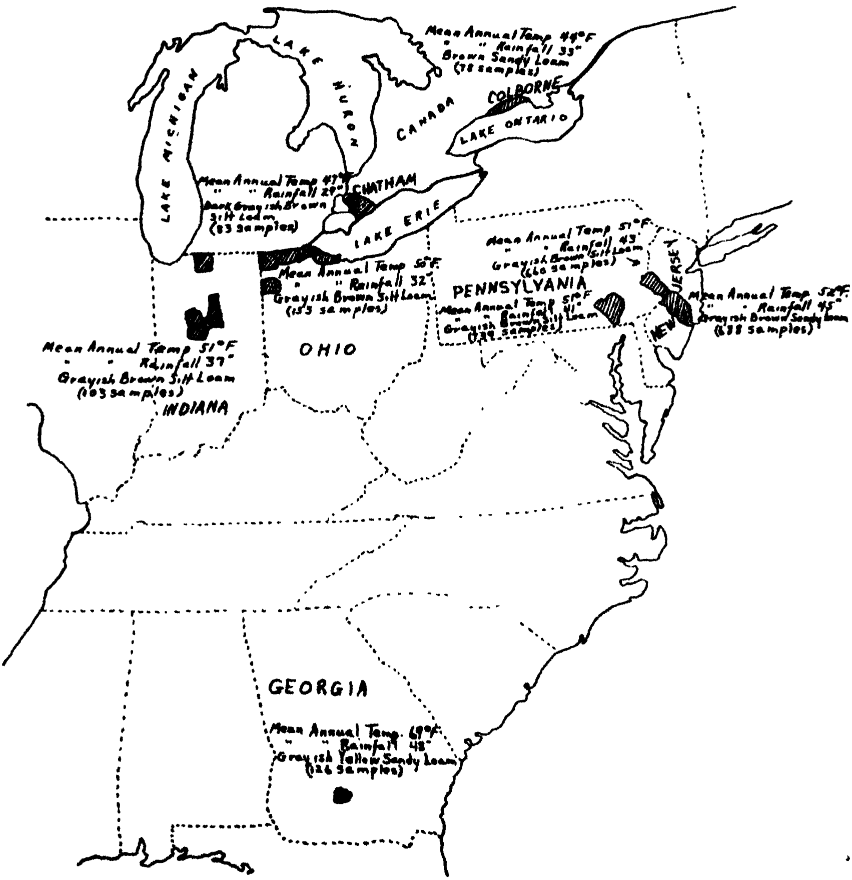

FIG. 1.—The distribution of soil samples and the mean annual rainfall and temperature of the respective areas.

1.67%. However, the fact should not be overlooked that the soils in New Jersey and Georgia were derived from non-calcareous materials while the ones in Colborne were from calcareous materials. The differences in pH values are shown in Table 2 and the differences in replaceable calcium in Table 3.

Undoubtedly, the high annual temperature and rainfall would cause the organic matter of the soils in the warmer climate to decompose faster and give up more nitrogen. This factor is perhaps largely responsible for establishing these organic matter content re-

TABLE 1.—*The influence of geographical location upon the organic matter content of sandy loam soils.*

Organic matter, %*	Percentage distribution		
	Colborne, Canada†	Burlington Co., N. J.‡	Tifton, Ga., §
–0.9	0	1	3
1.0–1.9	10	59	69
2.0–2.9	47	34	22
3.0–3.9	24	6	6
4.0–4.9	12	0	0
5.0–	7	0	0

*Organic matter determined by titration method (4).
†Predominating color of A_p horizon brown (Podsolic group). Soil type Dundonald. Parent material calcareous.
‡Predominating color of A_p horizon light brown to grayish brown (Gray-Brown podsolic group). Soil types Sassafras and Collington. Parent material non-calcareous.
§Predominating color of A_p horizon grayish yellow (Yellow soils group). Soil types Tifton and Norfolk. Parent material non-calcareous.

TABLE 2.—*The pH values of sandy loam soils in different locations.*

pH of soil*	Percentage distribution		
	Colborne, Canada	Burlington Co., N. J.	Tifton, Ga.
–4.9	0	4	1
5.0–5.4	0	35	34
5.5–5.9	3	48	51
6.0–6.4	19	11	14
6.5–6.9	31	2	0
7.0–7.4	11	0	0
7.5–7.9	36	0	0

*Glass electrode (1:2 soil-water relation).

TABLE 3.— *Replaceable calcium content of sandy loam soils in different locations.*

Replaceable CaO*	Percentage distribution		
	Colborne, Canada	Burlington Co., N. J.	Tifton, Ga.
– 499	0	13	57
500–1499	3	55	42
1500–	97	32	1

*Parts per two million (sodium acetate extract).

lations. Jenny (6) states that for every 18° F fall in temperature the nitrogen increased two or three times in the soil. From these figures the conclusion could be drawn that there is about twice as much nitrogen in Canadian soils as in Georgia soils.

SILTY LOAM SOILS

The variations in the organic matter content for the silty loam soils in Chatham, Canada (2, 11), Indiana, and Ohio are shown in Table

4. These data show that for a comparatively small change in temperature and rainfall a considerable difference in organic matter content is shown. Undoubtedly the type of agriculture and soil has influenced the organic matter content of these soils But, perhaps again, climate has been a more predominating factor. The distribution of these soils in respect to pH is shown in Table 5.

TABLE 4 —*The influence of geographical location upon the organic matter content of silty loam soils*

Organic matter, %	Percentage distribution	
	Chatham, Canada*	Ohio and Indiana†
2.9	0	6
3.0–3.9	0	11
4.0–4.9	6	26
5.0–5.9	23	28
6.0–6.9	30	20
7.0–7.9	18	8
8.0	22	0

*Predominating color of A_p horizon grayish brown (Podzolic group) Parent material calcareous Soil types Brookston and Thames

†Predominating color of A_p horizon grayish brown (Podzolic group) Parent material calcareous Soil types Brookston and Toledo

TABLE 5 —*The pH values of silty loam soils in two localities*

pH of soil	Percentage distribution	
	Chatham Canada	Ohio and Indiana
5.0–5.4	0	3
5.5–5.9	2	9
6.0–6.4	14	25
6.5–6.9	24	43
7.0–7.4	22	12
7.5–7.9	34	8
8.0	4	0

VARIATION OF ORGANIC MATTER CONTENT OF SILTY LOAM SOILS IN A LATERAL DIRECTION

Across the country the chief variation in climate is in the rainfall and humidity. In studying the organic matter content of the silt loam soils in this direction, soil samples from the following localities have been analyzed. Burlington County, New Jersey (1); Bucks County, Pennsylvania (9); Lancaster County, Pennsylvania (3); Toledo, Ohio (10, 12); and northern Indiana (13) Fig 1 gives the mean annual temperature and rainfall of each section

The results presented in Table 6 show that 99% of the well-drained silty loam soils in Burlington County are below 2.9% organic matter, whereas in Bucks County 86% are in the 2.0 to 3.9% group with a definite tendency toward the 2.0 to 2.9% group In Lancaster County 87% of the soils are in the 2.0 to 3.9% group, but in Ohio 63% of the soils are in the 5.0 to 6.9% group; whereas, in a slightly warmer sec-

tion of Indiana, 51% of the soils are in the 4.0 to 5.9% group. In Table 7 the pH value distribution of the soil samples is shown.

TABLE 6.—*The influence of geographical location upon the organic matter content of silt loam soils.*

Organic matter, %	Percentage distribution*				
	Burlington Co., N. J.	Bucks Co., Pa.	Lancaster Co., Pa.	Ohio	Indiana
1.0–1.9	48	14	8	0	3
2.0–2.9	51	63	55	0	13
3.0–3.9	1	23	32	6	19
4.0–4.9	0	0	5	22	30
5.0–5.9	0	0	0	34	21
6.0–6.9	0	0	0	29	8
7.0–7.9	0	0	0	10	6

*Predominating soil type in Burlington Co., N. J., Sassafras (including loams); Bucks Co., Pa., Penn (including loams); Lancaster Co., Pa., Hagerstown and Conestoga; Ohio, Toledo; Indiana, Brookston.

TABLE 7.—*The pH values of silty loam soils in various localities.*

pH of soil	Percentage distribution				
	Burlington Co., N. J.	Bucks Co., Pa.	Lancaster Co., Pa.	Ohio	Indiana
–4.9	8	7	0	0	0
5.0–5.4	38	26	3	2	4
5.5–5.9	36	30	31	6	14
6.0–6.4	15	22	53	23	29
6.5–6.9	3	10	12	47	37
7.0–7.4	0	5	0	14	9
7.5–	0	0	0	8	7

The difference in rainfall and humidity has influenced the amount of organic matter found in the soil in Burlington County, but perhaps the type of agriculture accounts for some decrease. Perhaps, longitudinally the temperature has been the predominating factor, whereas latitudinally rainfall has been the outstanding influence. It should be further pointed out that as one goes west to Ohio from New Jersey the silty loam soils become heavier. That is, soils in Burlington County just come into the silty loam class, whereas the ones in Ohio are tending to become clays. There was much more clay in the soils from Ohio and Indiana than in the ones from New Jersey and Pennsylvania.

DISCUSSION

The economic importance of organic matter in the soil has been fully appreciated and emphasized. Its destruction and incorporation in the soil has perhaps been overlooked. Owing to the difference in temperature more organic matter is probably necessary in a colder than in a warmer climate to furnish an equal amount of nitrogen for

crop growth. While the data in this paper are greatly lacking in what influence man has had in changing the organic matter content of the soil, they show the variations in the different sections and their probable relation to climate.

SUMMARY

Data are given to show the organic matter content and pH value of certain soils in various sections of the United States and southern Canada. Attention has been called to the variation in climatic conditions in the sections considered.

LITERATURE CITED

1. BURKE, R. T. A., and LEE, L. L. Soil survey of the Camden area, New Jersey. U. S. D. A. Series 1926 No. 28. 1926.
2. CHAPMAN, L. J., and PUTNAM, D. F. The soils of south-central Ontario. Sci. Agr., 18:161–197. 1937.
3. GILBERT, B. D., *et al.* Soil survey of Lancaster County, Pennsylvania. U. S. D. A. 1916.
4. HESTER, J. B. The relation of soil texture and color to the organic matter content. Soil Sci. Soc. Amer. Proc., 3:112-114. 1938.
5. ———— and SHELTON, F. A. Soil organic matter investigations upon Coastal Plain soils. Va. Truck Exp. Sta. Bul. 94. 1937.
6. JENNY, H. Relation of climatic factors to the amount of nitrogen in the soil. Jour. Amer. Soc. Agron., 20:900–912. 1928.
7. JOFFE, J. S. Pedology. Rutgers University Press. 1936.
8. KELLOGG, C. E. Development and significance of the great soil groups of the United States. U. S. D. A. Misc. Pub. 229. 1936.
9. MARBUT, C. F. Atlas of American Agriculture, Part III. Soils of the United States. U. S. D. A. Bur. Chem. & Soils. 1935.
10. PASCHALL, A. H., *et al.* Soil survey of Ottawa County, Ohio. U. S. D. A. Series 1928 No. 26. 1928.
11. PUTNAM, D. F., and CHAPMAN, L. J. The climate of southern Ontario. Sci. Agr., 18:401–446. 1938.
12. TAYLOR, A. E., *et al.* Soil survey of Fulton County, Ohio. U. S. D. A. 1928.
13. THARP, W. E., *et al.* Part I. Soil survey of Miami County, Indiana. Part II. The management of Miami County soils. U. S. D. A. Series 1927 No. 24. 1927.

EFFECT OF DIFFERENT TEMPERATURES ON THE GERMINATION OF SEVERAL WINTER ANNUAL SPECIES OF TRIFOLIUM[1]

E. H. TOOLE AND E. A. HOLLOWELL[2]

THROUGHOUT the southern, south central, and Pacific states many winter annual Trifolium species, such as *T. dubium*, least hop clover, *T. procumbens*, low hop clover, *T. resupinatum*, Persian clover, *T. subterraneum*, subterranean clover, and *T. glomeratum*, cluster clover, are perpetuated from year to year by self-seeding in early summer and volunteering during the fall months. This occurs, however, to a degree making these clovers of agricultural importance only after a seed equilibrium has been established in which germinable seed are present in sufficient numbers to produce good stands. The seed coats of nearly all these species are "hard", making them impermeable to moisture; therefore, they must be scarified either through the action of weathering or by abrasion. Others are relatively "soft seeded" and will germinate without scarification. Under natural conditions it is believed that most of the "hard" seed is softened by the weathering process and is germinable during the spring and summer months. However, plants of these species are conspicuously absent from the flora during the summer months. Most seed of crimson clover, *T. incarnatum*, another winter annual, will germinate when planted or from volunteer seeding at any time during the summer. In the southern states insufficient moisture is not often a limiting factor in germination during this period.

This study, a phase of a life history project of the Division of Forage Crops and Diseases, was designed to determine the effect of different temperatures on germination under laboratory conditions where the control of temperatures is possible. High summer soil temperatures may be responsible for live permeable seed remaining dormant until fall or until the occurrence of cool weather.

METHODS

During June 1935, seed of low hop clover, Persian clover, cluster clover, and buffalo clover, *T. reflexum*, was gently hand stripped from standing plants without being scarified in any way. Seed of subterranean clover was harvested by raking the buried pods from the soil and while this method of harvesting might scarify some of the seed, facilities did not permit other treatment. The seed was hulled by gently rubbing it in the palm of the hand. Each seed lot was divided into two parts, one part was scarified by rubbing the seed between sand paper while the other part was not scarified.

The seeds were stored in small paper envelopes in the laboratory and monthly germination tests were made beginning July 1935 and continuing through February 1936, for the scarified seed of Persian clover, cluster clover, and buffalo clover, and through December 1935 for the unscarified seed of the above three

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species and for both lots of low hop clover. Only enough seed was available for three tests of each lot of subterranean clover. Additional tests were made in September 1937 and July 1938 of all lots except subterranean clover.

Duplicate tests, using 100 seeds each, were made between moistened blotting paper at 35°, 30°, 25°, 20°, 15°, and 10° C in germination chambers maintained within 1° C of the stated temperature. The tests at 5° C were kept in a refrigerator where the temperature varied from 3° to 6° C. The tests were continued for 28 days, except for the first two months, when the tests at some of the higher temperatures were transferred to lower temperatures after 21 days.

The viability of the scarified seed had declined before the 1937 and 1938 tests were made and, therefore, these results are not included in the averages of the germination at the different temperatures but are given to indicate the rate of loss of viability under laboratory storage.

RESULTS

The results of the germination tests for all five species are presented in Tables 1 and 2, but the results for each species will be discussed separately.

PERSIAN CLOVER

Scarified seed.- Scarification of this sample was nearly complete so that practically no hard seed remained. Germination was essentially the same at the four temperatures 25°, 20°, 15°, and 10°, except for the first test at 25°. Germination at 30° and at 35° was variable, but in all cases appreciably lower than at 20°. The unfavorable effect of the higher temperatures, 35° and 30° and to some extent 25°, is shown by the comparatively low germination during the first 6 days in comparison with the almost complete germination during this period at 20°, 15°, and 10°. Germination at 5° was somewhat erratic which fact will be explained in the general discussion. After two and especially after three years, loss of viability of the seed was considerable.

Unscarified seed.—No appreciable loss of viability of the unscarified seed was observed after 3 years. During the early months of the experiment a few seed absorbed water, but differences in germination at different temperatures were not evident. Beginning with the November 1935 test, however, a gradual softening of the hard seeds occurred and this, as shown graphically in Fig. 1, was progressively greater at the lower temperatures.

CLUSTER CLOVER

Scarified seed.—Germination of this species for the first 8 months was essentially the same at the three temperatures 20°, 15°, and 10°. During the early months, germination at 25° averaged decidedly lower than at 20°, but in October it was as high at 25° as at the lower temperatures. Germination was markedly lower at 30° and 35°. The progressive change of germination of the seed in this sample at 20°, 25°, and 30°, as shown in Fig. 2, is hard to explain, unless it was influenced by changes in the humidity of the laboratory where the seed was stored. As with the preceding species, the differences at the

TABLE I.—*Average percentage germination and percentage hard seed in 28 days of successive tests of scarified samples of five species of Trifolium.*

Germination temperature, °C	1935												1936				Average of all tests in 1935 and 1936		1937		1938	
	July		August		September		October		November		December		January		February				September		July	
	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed
											Persian Clover											
35	—	—	51*	0	81	0	74	0	72	0	82	0	76	0	91	0	75.3	0	64	0	31	0
30	66*	0	78	0	80	0	89	0	60	0	61	0	73	0	84	0	72.8	0	—	0	48	0
25	76	0	97	0	98	0	97	0	98	0	91	0	95	0	96	0	93.5	0	76	0	62	0
20	94	1	99	0	98	0	96	0	97	0	96	0	97	0	97	0	96.8	0	88	0	65	0
15	92	0	94	0	97	0	97	0	97	0	98	0	97	0	98	0	96.3	0	86	0	55	0
10	97	0	97	0	94	0	96	0	97	0	92	0	97	0	94	0	95.5	0	81	0	46	0
5	95	1	88	0	95	0	90	0	89	0	83	0	91	0	81	0	89.0	0	52	0	40	0
Av.	86	0	86	0	91	0	90	0	87	0	86	0	89	0	91	0						
											Cluster Clover											
35	—	—	5*	15	16	12	22	9	17	12	8	9	7	8	9	11	12.0	10.9	2	15	6	19
30	19*	20	8*	19	42	14	39	12	16	12	18	11	18	14	21	14	22.6	14.5	—	14	23	10
25	22	16	48	11	69	13	84	10	75	11	56	15	43	10	47	15	55.5	12.6	57	14	58	21
20	74	24	78	17	83	12	86	12	84	12	82	17	78	17	77	19	80.3	16.3	67	23	66	23
15	68	29	76	21	83	15	80	19	76	18	78	21	79	19	78	20	77.3	20.3	67	27	55	21
10	75	25	81	19	78	13	80	19	75	18	74	22	75	19	67	28	75.6	20.4	62	29	59	21
5	65	32	69	25	56	24	68	21	66	21	69	28	40	31	33	35	58.3	27.1	42	32	48	26
Av.	53	24	52	18	61	14	65	14	58	14	55	17	48	16	47	20						

Buffalo Clover

35	—	—	5*	10	9	7	10	7	3	11	—	—	3	6	6	8	6.0	8.2	2	9	4	8
30	17*	8	9*	7	51	8	32	9	21	7	27	11	42	4	58	7	32.1	7.6	—	17	40	12
25	51	6	72	5	82	11	91	6	86	10	90	10	88	11	87	9	80.9	8.5	68	15	50	13
20	87	8	91	8	87	11	87	11	88	12	84	13	90	8	84	15	87.3	10.8	71	12	53	15
15	86	12	85	14	89	9	91	7	87	11	84	14	90	9	87	11	87.4	10.9	55	15	45	15
10	83	16	86	13	88	10	87	10	89	11	86	13	86	12	87	12	86.5	12.1	56	15	49	19
5	81	11	78	14	72	14	88	9	75	15	75	13	34	11	31	22	66.8	13.8	38	15	31	15
Av.	67	10	60	10	68	10	69	8	64	11	74	12	61	8	62	12						

Subterranean Clover

30	0*	1	4*	4	12	6	—	—	—	—	—	—	—	—	—	—	5.3	3.7	—	—	—	—
25	4	1	6*	2	6	2	—	—	—	—	—	—	—	—	—	—	5.3	1.7	—	—	—	—
20	97	2	98	1	97	3	—	—	—	—	—	—	—	—	—	—	97.3	2.0	—	—	—	—
15	95	4	95	4	91	6	—	—	—	—	—	—	—	—	—	—	93.7	4.7	—	—	—	—
10	95	3	96	2	93	4	—	—	—	—	—	—	—	—	—	—	94.7	3.0	—	—	—	—
5	94	4	93	5	95	3	—	—	—	—	—	—	—	—	—	—	94.0	4.0	—	—	—	—
Av	64	2	65	3	56	4	—	—	—	—	—	—	—	—	—	—						

Low Hop Clover

35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	30	0	35
30	0*	30	0*	30	1	25	1	32	1	24	1	37	—	—	—	—	0.7	29.7	2	29	0	—
25	2	34	1*	24	9	22	3	31	12	32	5	31	—	—	—	—	5.3	29.0	2	30	1	38
20	62	36	59	41	62	33	65	33	65	29	62	34		—	—	—	62.5	34.3	32	44	48	39
15	59	39	60	36	66	32	60	38	59	40	64	34	—	—	—	—	61.3	36.5	54	35	50	36
10	67	32	51	49	40†	33	59	38	64	32	62	36	—	—	—	—	58.7	36.7	63	28	49	41
5	53	47	52	46	50	41	47	44	37	44	26	44	—	—	—	—	44.3	44.3	24	45	25	42
Av	40	36	37	37	39	31	39	36	39	33	36	36	—	—	—	—						

*Germination and hard seed at 21 days instead of 28 days
†14% watery abnormal seedlings

TABLE 2.—*Average percentage germination and percentage hard seed in 28 days of successive tests of unscarified samples of five species of Trifolium.*

Germination temperature, °C	1935												1937		1938		Average of 8 tests	
	July		August		September		October		November		December		September		July			
	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed	Germination	Hard seed
									Persian Clover									
35	—	—	—	—	—	—	—	—	—	—	11	80	8	81	6	80	—	—
30	3	96	2	96	6	93	2	95	2	92	7	84	17	79	13	81	6.5	89.5
25	3	94	2	97	4	95	1	97	10	87	10	88	8	81	12	82	6.3	90.1
20	6	93	9	91	7	92	4	95	6	93	13	86	19	79	18	75	10.3	88.0
15	2	96	4	96	6	93	7	93	6	93	20	79	25	72	21	75	11.4	87.1
10	5	93	1	97	7	92	2	98	13	86	25	73	25	70	33	62	13.9	83.9
5	5	95	3	96	5	94	4	95	10	.88	18	75	39	53	51	44	16.9	80.0
Av*...	4	95	4	96	6	93	3	96	8	90	16	81	22	72	25	70		
									Cluster Clover									
35	—	—	—	—	—	—	—	—	—	—	0	82	0	85	0	89		
30	4	86	3	86	2	83	0	85	3	86	1	91	7	86	1	89	2.6	89.0
25	1	89	4	82	11	78	8	88	8	85	4	90	2	94	1	93	3.9	87.4
20	9	89	6	92	10	83	8	90	12	87	4	94	5	93	3	92	7.1	90.0
15	4	95	14	88	10	90	5	94	5	91	5	94	6	91	2	95	6.4	92.3
10	6	93	6	93	7	89	5	95	7	85	1	98	4	91	1	93	4.4	92.1
5	3	96	6	94	4	92	4	95	4	92	4	94	1	95	1	93	3.4	93.9
Av*....	5	91	7	89	7	86	5	91	7	88	3	94	4	92	2	93		

Buffalo Clover

35	—	—	—	—	—	—	—	—	—	—	—	—	0	96	1	95		
30	0	97	0	97	4	94	2	95	2	95	1	94	1	97	0	96	1.3	95.6
25	2	92	2	95	3	95	3	96	5	92	3	96	1	97	1	97	2.5	95.0
20	3	96	2	97	4	94	5	94	3	95	3	96	2	96	1	98	2.9	95.6
15	3	95	1	97	4	96	4	94	3	95	2	96	1	97	1	97	2.4	95.9
10	2	93	3	94	3	95	2	97	2	98	3	95	0	96	1	96	2.0	95.5
5	1	97	2	95	2	97	2	95	1	97	0	96	0	96	0	98	1.0	96.4
Av.*....	2	95	2	96	3	95	3	95	3	95	2	96	1	97	1	97		

Subterranean Clover

30	1	43	1	39	0	39	—	—	—	—	—	—	—	—	—	—	0.7	40.3
25	0	36	2	39	1	37	—	—	—	—	—	—	—	—	—	—	1.0	37.3
20	62	37	53	46	63	34	—	—	—	—	—	—	—	—	—	—	59.3	39.0
15	62	37	55	44	57	41	—	—	—	—	—	—	—	—	—	—	58.0	40.7
10	46	48	60	37	57	41	—	—	—	—	—	—	—	—	—	—	54.3	42.0
5	59	39	59	39	55	41	—	—	—	—	—	—	—	—	—	—	57.7	39.7
Av.....	38	40	38	41	39	39	—	—	—	—	—	—	—	—	—	—		

Low Hop Clover

35	—	—	—	—	—	—	—	—	—	—	—	—	0	85	0	87	—	—
30	0	81	0	88	0	83	0	80	0	83	0	80	0	82	0	84	0.0	82.6
25	0	84	0	87	0	89	0	88	1	88	2	84	0	83	0	82	0.4	85.6
20	9	89	5	94	5	93	10	88	7	92	12	86	13	81	6	89	8.4	89.0
15	9	89	9	90	9	90	7	91	6	93	18	81	20	79	16	80	11.8	86.6
10	7	91	10	89	14	84	13	86	24	74	21	77	30	64	12	84	16.4	81.1
5	4	95	11	88	10	83	9	89	3	91	3	82	6	74	8	77	6.8	84.9
Av.*....	5	88	6	89	6	87	7	87	7	87	9	82	12	77	7	83		

*Readings at 35° not included in averages.

various temperatures were even more marked when the results at the end of 6 days are compared. Table 3 shows that germination at 5° was low, accounted for, in part, by the increased number of hard seed at this temperature. The average percentage of hard seeds for the first 8 months for different temperatures of germination showed in general a larger number of hard seeds remaining as the temperature

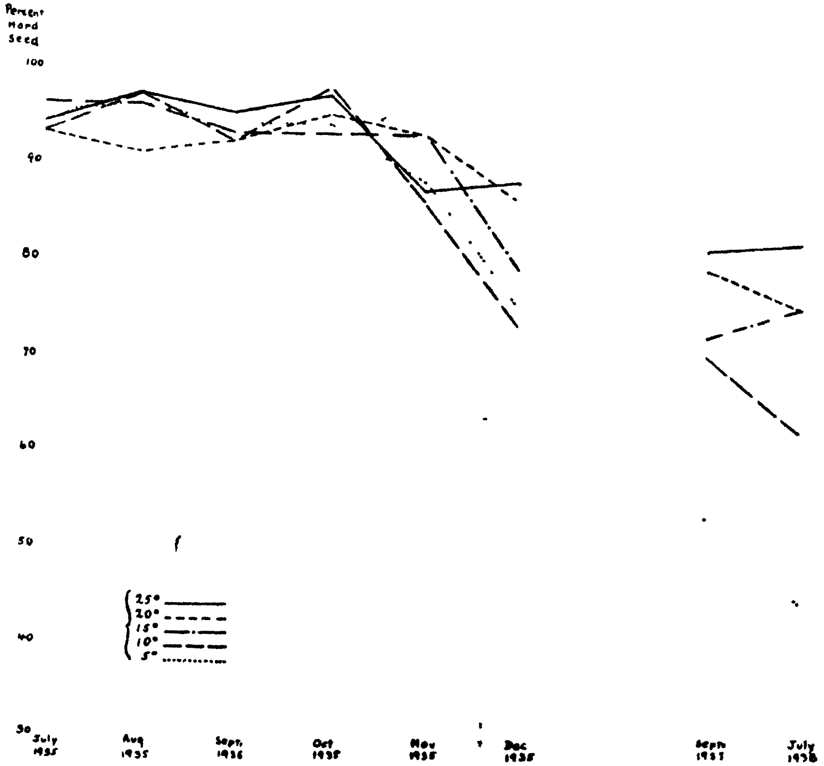

FIG. 1.—Effect of age on percentage of hard seed in a nonscarified sample of Persian clover seed when germinated a different temperatures.

was lowered. A considerable difference in the number of hard seed occurred during the different months of test. This variation was in general inversely proportional to the progressive changes in germination at 20° illustrated in Fig. 2.

Unscarified seed.—Over the entire period of the test the unscarified seed of this species did not show striking or consistent variations in germination or hard seed content.

BUFFALO CLOVER

Scarified seed.—At 25° germination increased progressively for the first four months in contrast to the essentially uniform germination at 20°, 15°, and 10°. This progressive improvement in germination at

25° is especially marked when the results at 6 days are compared, as shown in Table 3. Germination was much lower at 30° and at 35°. As shown in Fig. 3, wide unexplained progressive fluctuations of germination occurred at 30°. At 5° germination was often accompanied by the development of watery seedlings. It was apparent that 5° was too low a temperature for the development of normal seedlings of this species.

TABLE 3.—*Average percentage germination in 6 days of successive tests of scarified samples of three species of Trifolium.*

Germination temperature, °C	Percentage germination							
	July 1935	Aug 1935	Sept. 1935	Oct. 1935	Nov 1935	Dec. 1935	Jan. 1936	Feb. 1936
	Persian Clover							
35	–	5	4	3	7	3	1	2
30	13	10	48	22	18	9	26	24
25	32	84	95	85	91	52	70	96
20	94	99	98	96	97	96	97	97
15	91	94	97	97	97	98	97	98
10	95	97	94	96	97	92	88	93
5	80	72	0	0	0	0	0	0
	Cluster Clover							
35		2	1	4	2	1	1	1
30	0	0	2	8	2	0	1	2
25	0	4	16	47	40	1	7	8
20	58	67	75	79	72	69	61	67
15	53	65	75	70	68	65	69	67
10	62	72	68	69	62	58	53	50
5	31	22	0	0	0	0	0	0
	Buffalo Clover							
35		0	1	0	0	--	0	0
30	0	1	21	2	10	13	29	4
25	5	30	66	87	80	81	79	82
20	82	87	85	85	85	82	85	79
15	78	82	88	89	85	81	87	84
10	74	81	84	85	86	82	63	57
5	0	0	0	0	0	0	0	0

With this species the mean hard seed content at the different temperatures of germination shows differences, some of which are significant. As with cluster clover, there is an increased number of hard seed at the lower temperatures, although the difference between the upper and lower temperatures is not great.

After two and three years storage a decided fall in germination and a slight increase of hard seeds were observed.

Unscarified seed.—As with cluster clover the unscarified seed did not vary appreciably in germination or hard seed, either at the different temperatures or for the different months of the test.

SUBTERRANEAN CLOVER

Scarified seed.—This species showed a sharp response to temperature of germination. Germination was high at 20° and at all the lower

temperatures but was almost negligible at 25° and 30°. At these temperatures the seeds were swollen but remained dormant. Comparative tests at 20° and 25° with a number of other samples of this species

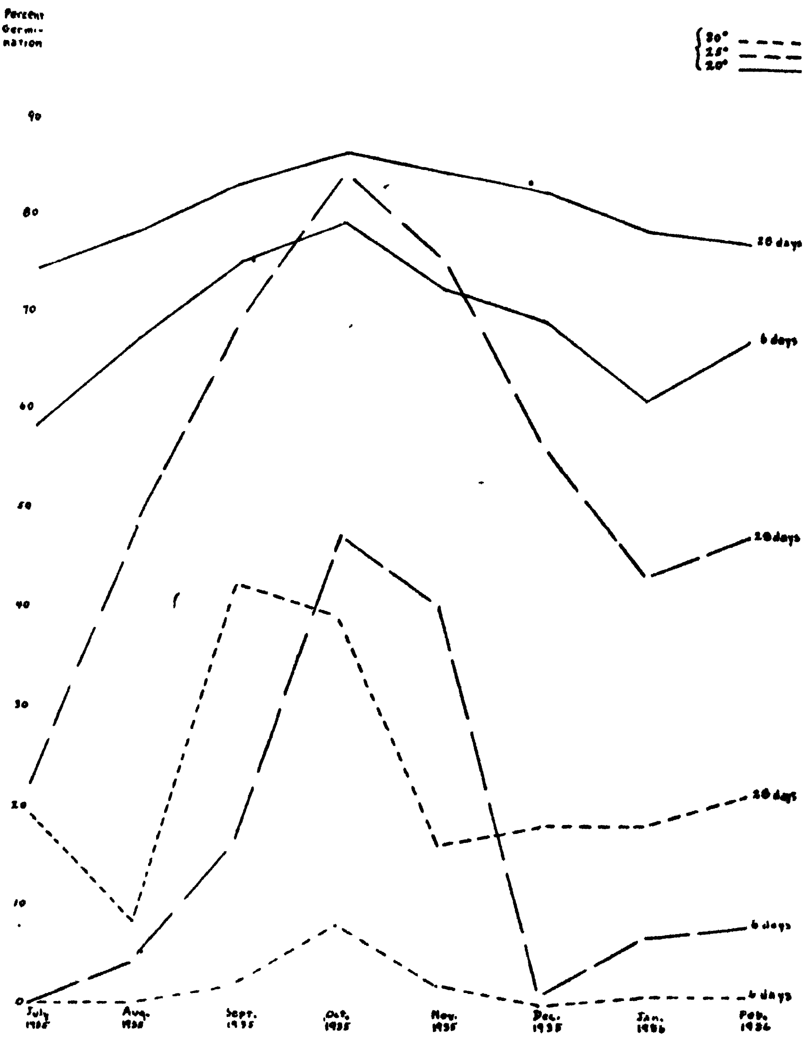

FIG. 2.—Comparison of germination percentages for 6 and 28 day periods of successive monthly tests of scarified cluster clover seed when germinated at temperatures of 20°, 25°, and 30° C.

have shown the same temperature response. At the favorable temperatures germination was practically completed in 6 days.

Unscarified seed.—At favorable temperatures the germination of this sample was above 50%. Since this sample was not hand harvested

it is not known whether the germinating seed represented naturally "soft" or scarified seed. The same sharp response to temperature differentials is shown as with the scarified seed.

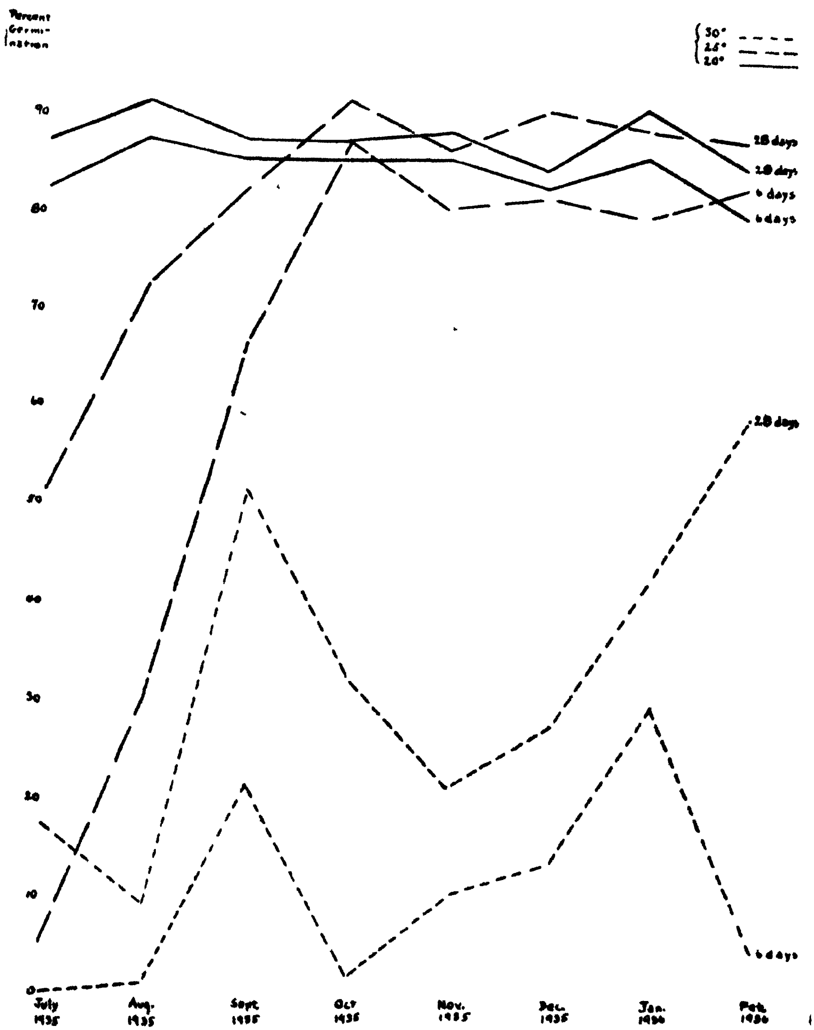

FIG. 3.—Comparison of germination percentages for 6- and 28-day periods of successive monthly tests of scarified buffalo clover seed when germinated at temperatures of 20°, 25°, and 30° C.

LOW HOP CLOVER

Scarified seed.—Scarification of the very small seed of this species was not at all complete. This species also shows a striking germination response to temperature. At 25° and 30° germination was very

low, but was essentially the same at 20°, 15°, and 10°. As with buffalo clover, 5° was too low for development of normal seedlings.

As with cluster clover and buffalo clover, the hard seed increased in number with lowered germination temperatures. The loss of viability after 2 and 3 years is not as marked as for some of the other species.

Unscarified seed.—Although the percentage of seeds that absorbed water was comparatively low, the same sharp difference in germination was evident in seed tested at 25° and 20°. A tendency for an increased softening of the hard seeds at the lower temperatures is shown especially at 10°, but the results are not consistent enough to consider this tendency significant.

CRIMSON CLOVER

Unscarified seed.—In 1938 a small sample of crimson clover seed was hand harvested and germinated without scarification at the same temperature differentials as used for the other species. Approximately 50% of the seed took up water and germinated and no significant difference in germination at different tempeatures was apparent. At a temperature of 35° C fewer seed remained hard and at 30° germination was somewhat slower than at 25° and below.

DISCUSSION

LABORATORY GERMINATION

Of the five species under study, subterranean clover and low hop clover showed the sharpest differences in germination at different temperatures. Both species germinated well at 20° or lower, but at 25° or higher germination was very low.

Buffalo clover germinated as well at 25° as at 20° and even at 30° germination averaged 30% for the 8 monthly tests. The response of cluster clover was somewhat similar to that of buffalo clover except for the excessive variation at 25° for the different months. Persian clover was least affected by temperature of germination, although considerable variation was evident in the monthly results. This species averaged more than 70% germination at both 30° and 35° for the first 8 months tested, but germination was much slower than at the lower temperatures.

No significant variation in germination was apparent in the successive monthly tests at 20°, 15°, and 10° of the scarified seed of Persian clover, buffalo clover, subterranean clover, and low hop clover. Germination at 25° tended to increase during the first three months of test for Persian clover, cluster clover, and buffalo clover, which may indicate dormancy at high germination temperatures immediately after harvest. This condition lasted for a period of from one to three months.

The germination of cluster clover seed tested at 20° and 25° consistently increased until October and then gradually decreased. The change at 30° was similar but germination at all times was much lower. As previously stated these changes are in part reflected in the monthly averages of hard seed for this species. The other species did not show this subsequent reduction in germination.

The four species tested in September 1937 and in July 1938 showed a more or less marked reduction in viability of the scarified samples, but no definite change in response to temperature.

Because of the slow germination at the higher temperatures and at 5° the tests were continued for 28 days. At 20° very little increase of germination occurred after 6 days, but at the higher temperatures a great deal of the germination occurred after this time. Table 3, showing the comparative germination at 6 days, emphasizes the difference in rate of germination at the various temperatures. This table also emphasizes the progressive improvement in germination of Persian clover and buffalo clover for the first months at 25°. Since subterranean clover and low hop clover germinated very poorly at the higher temperatures, these species are not included in Table 3.

The refrigerator, used for the temperature designated as 5°, varied in temperature more than the other chambers. This temperature variation accounts in part for the erratic results at 5°. Also, the seedlings of cluster clover, buffalo clover, and low hop clover produced at this low temperature were stunted and watery. Considerable variation existed in interpreting the condition of these sprouts in the different tests. Persian clover and subterranean clover produced fairly normal seedlings at this low temperature.

It has been suggested by Davis[8] that some kinds of seeds held moist at a temperature too high for germination are thrown into secondary dormancy after which a lower than normal temperature is required for germination In conducting the first two series of tests, the seeds which did not germinate in 21 days at 30° and 35° were transferred to 20° and to 10° In general the germination of the sound seed was prompt and complete at both temperatures. However, with low hop clover germination was much quicker when the seeds from a high temperature were transferred to 10° than when transferred to 20°, indicating a possible secondary dormancy after holding the moist seed at a high temperature.

As previously stated, there was in the scarified samples of cluster clover, buffalo clover, and low hop clover a significant difference between the average hard seed content of seed germinated at low and high temperatures. The tendency was for a greater number of hard seed to germinate at the lower than at the higher temperatures which is in striking contrast to the tendency in the unscarified sample of Persian clover where, during the later months, less hard seed occurred at the low temperatures. Since practically no hard seeds were present in the scarified sample of the latter species, a direct comparison of the behavior of the hard seeds of scarified and non-scarified samples is impossible.

RELATIONSHIPS OF SOIL TEMPERATURES TO FIELD GERMINATION

In attempting to correlate the results of these studies with field

[8]Davis, W. E. Primary dormancy, after ripening and the development of secondary dormancy in embryos of *Ambrosia trifida*. Amer. Jour. Bot., 17:58–76. 1930.

———. The development of dormancy in seeds of cocklebur (Xanthium). Amer. Jour. Bot., 17:77–87. 1930.

behavior, other ecological factors such as moisture, soil type, and the amount of solar energy are either directly or indirectly related to soil temperatures. Furthermore, under natural conditions, diurnal variation in surface soil temperatures is often very great. The extent of its effect on germinating seed is not known. With the exception of subterranean clover the seeds of the species studied are very small and the seeds must be on or near the soil surface for germination. The surface soil temperatures are therefore most important for the small-seeded species and temperatures one-half inch under the surface for the larger seeded species. So far as known continuous soil temperature records for the surface or slightly thereunder have not been taken in the southern states. In connection with other investigations continuous soil temperature records were taken at Columbia, Mo., during the spring, summer, and fall months of 1937 at a depth of one-half inch under the soil surface and are presented in Table 4.[4] The mean air temperatures of 1937 at Columbia, Mo , for the months of March and April were slightly below the normal mean, while they were above normal for the months of May, June, July, August, and September.

Surface soil temperatures are subject to greater variation than those below the surface and for that reason the average daily maximum temperatures at the surface would doubtless be higher and would occur somewhat earlier in the spring than the temperatures as shown in the records presented in Table 4 at one-half inch below the surface. If maximum soil temperatures are used as a basis of analyses, the period May 1 to 15 would be unfavorable for the germination of low hop clover and subterranean clover but favorable for the other species This is shown by the results of experiments in which germination of the former species was sharply inhibited at a 25° temperature level. A similar analysis of the temperature records for the fall months indicates that the period of October 16 to 31 would be the most favorable for germination. Of the species investigated low hop clover has been the only one successfully established at Columbia, Mo.

In previous date of planting experiments[5] at Statesville, N. C., stands have resulted from a single March planting; however the plants made only a meager growth, blossomed, and set seed sparingly. As shown by the results of this study response to different soil temperatures may be one of the contributing factors in species adaptation. Late spring germination of those species less sensitive to the inhibiting effects of high temperatures would occur at a time when other unfavorable factors for growth, such as length of day and competition from other plants, would be of increasing intensity. However, in the fall a decreasing gradient from high to low temperatures occurs and this provides favorable conditions. In the south soil temperatures are favorable for germination over a long period of time in the late fall and winter months and the fact that most winter annuals thrive in such an environment may indicate that a long period of exposure

[4]The authors are indebted to Dr. E. M. Brown for permission to use the records as presented in Table 4.

[5]The establishment of low hop clover, *Trifolium procumbens*, as affected by time of seeding and growth of associated grass. Jour. Amer. Soc. Agron., 30:589–598. 1938.

TABLE 4.—*Average mean and daily maximum air temperatures taken 6 inches above a Kentucky bluegrass sod and bare soil temperatures taken ½ inch below the soil surface at Columbia, Mo., 1937.*

Period	Temperatures, °C				Maximum soil temperatures in °C by days of the month*															
	Av. air	Av. max. air	Av. soil	Av. max. soil	1 16	2 17	3 18	4 19	5 20	6 21	7 22	8 23	9 24	10 25	11 26	12 27	13 28	14 29	15 30	31 31
Mar. 1–15	4	9	4	11	9	16	16	**12**	19	18	21	*11*	11	12	*10*	*11*	**1**	1	**2**	
Mar. 16–31	4	9	5	10	1	*12*	18	**10**	*6*	17	18	*16*	*14*	*7*	*2*	*1*	*6*	*8*	**8**	16
Apr. 1–15	9	14	8	14	*7*	18	*19*	**6**	**6**	19	*12*	**11**	*14*	18	21	**11**	23	—†	—†	
Apr. 16–30	13	18	11	17	—†	—†	—†	25	**14**	22	23	23	**10**	**6**	**8**	18	**10**	*22*	23	
May 1–15	14	19	16	24	*23*	**16**	**16**	*24*	23	28	28	*22*	27	29	26	*25*	*20*	*26*	*25*	
May 16–31	21	26	21	31	*28*	*29*	33	*31*	36	**23**	*27*	31	29	*30*	*26*	27	34	35	34	*36*
June 1–15	18	24	19	27	*38*	*33*	**20**	*31*	*27*	24	30	*31*	**19**	**20**	*26*	*30*	*29*	30	**23**	
June 16–30	25	31	26	36	*31*	33	33	35	33	34	35	41	41	38	41	*36*	39	36	33	
July 1–15	26	33	29	41	*38*	39	*29*	40	43	42	43	42	44	43	*39*	*37*	42	*44*	43	
July 16–31	25	31	28	40	45	*34*	38	34	38	39	41	42	*36*	34	39	41	43	46	46	43
Aug. 1–15	27	33	29	42	*36*	39	*47*	*38*	46	38	*35*	43	44	*38*	45	43	46	46	47	
Aug. 16–31	27	34	30	44	47	49	49	46	*38*	*36*	*35*	*40*	43	46	46	48	47	44	43	48
Sept. 1–15	23	31	26	39	*49*	46	*46*	40	*34*	43	42	*43*	*41*	32	37	34	37	38	*34*	
Sept. 16–30	18	26	18	29	31	31	33	33	34	31	35	**31**	**21**	23	24	26	*19*	29	32	
Oct. 1–15	14	21	16	25	34	35	**23**	**24**	32	*29*	27	*22*	*22*	25	27	*26*	*19*	18	**11**	
Oct. 16–31	11	17	11	19	**16**	**15**	*24*	*17*	*17*	**13**	**7**	13	*21*	22	20	20	*22*	26	26	23

*Plain type indicates the occurrence of 65 to 100% possible sunshine for the day indicated; italic type indicates the occurrence of 10 to 65% possible sunshine; and bold face type indicates the occurrence of from 0 to 10% possible sunshine.

†Temperature recorder was out of commission during the period April 14 to 18, inc.

with normal variations of temperature may be necessary to provide the required combination of factors favorable to germination.

Since white clover, *T. repens*, behaves principally as a winter annual in the south, high temperature may be an inhibiting factor in its germination, though observations have indicated that it is not as adversely affected by high temperatures as low hop clover or subterranean clover.

If perchance the hard seed of the species studied is softened by the effects of summer temperatures, light, and moisture after maturing in late spring, high soil temperatures, as shown by these studies, would undoubtedly inhibit its germinating until fall.

SUMMARY

Seed of low hop clover, cluster clover, subterranean clover, Persian clover, and buffalo clover was hand harvested, separated in two parts, one of which was scarified and the other left unscarified. Samples from both scarified and unscarified seed of each species were germinated under controlled laboratory conditions at temperatures of 35° C, 30° C, 25° C, 20° C, 15° C, 10° C, and 5° C, for 28-day periods at monthly intervals beginning in July and continuing for 8 months and after 2 and 3 years. Unscarified seed of crimson clover hand harvested was germinated for one period at the above temperature differentials. Percentages of germination and hard seed are reported after 6 days in test and at the end of the 28-day period.

SCARIFIED SEED

The germination of the scarified seed of all species studied was inhibited in varying degrees by the temperatures of 30° and 35° C.

At 20° and at the lower temperatures subterranean clover and low hop clover germinated well, while at 25° the germination was very low.

The germination of cluster clover was appreciably lower at 25° than at 20° except for the October and November tests. Also a marked reduction in germination occurred between the 25° and 30° and between the 30° and 35° temperatures.

Buffalo clover germinated practically as well at 25° as at 20° while at 30° a decrease in percentages from 80 to 32 occurred.

Persian clover was least affected by temperature of germination for the germination averaged more than 70% at both the 30° and 35° tests.

In general, germination at 25° increased during the first three months of test for Persian clover and buffalo clover, while for cluster clover the increase occurred through October but after November a definite decrease occurred. This reduction in germination did not occur for Persian clover and buffalo clover.

A marked reduction in the viability of the seed of the four species tested had occurred when germinated in September 1937 and in July 1938.

At the 5° temperature the sprouts of cluster clover, buffalo clover, and low hop clover were somewhat stunted and watery while those of the Persian clover and subterranean clover appeared normal.

After 21 days swollen non-germinating seed at the 30° and 35° tests for the first two months were transferred to the 20° and 10° chambers where germination was rapid and complete at either temperature for all species except low hop clover. The swollen seeds of this species germinated much faster when transferred to 10° than 20° indicating a dormancy induced by the high temperature.

UNSCARIFIED SEED

The hard seed content of the unscarified seed of the five species studied was not affected by the temperature gradients or period tested except Persian clover. Beginning with the November test a gradual softening of the hard seed of Persian clover occurred and this was progressively greater at the lower temperatures and was the most pronounced after the second and third year.

The one test with crimson clover seed made three months after harvest indicated that a high percentage of the seed was soft and that there was no significant difference in germination at the different temperatures.

An analysis of continuous soil temperature records taken at Columbia, Mo., and the results of these germination studies at different temperatures clearly show that high summer soil temperatures inhibit the germination of the species studied except crimson clover.

IDENTIFICATION OF STANDARD AND FAIRWAY STRAINS OF CRESTED WHEATGRASS[1]

W. D. HAY[2]

CRESTED wheatgrass, *Agropyron cristatum* (L.) Beauv., has spread rapidly in Montana and other western states during recent years. It is a hardy drought-resistant grass particularly valuable for dryland pasture and has been extensively used for re-grassing abandoned cultivated lands. Two strains, S.P.I. 19537 and Saskatchewan 1350, known respectively as Standard and Fairway, are grown and handled commercially. Because of their different adaptations and uses, it is often necessary to distinguish between these two strains in order to detect substitutions or mixtures.

Studies have been made of the comparative morphology of the seeds, of plants in the seedling stage, and of headed plants in the field during the past 3 years. In making this study, approximately 500 seed samples were examined, 100 seedling plants were studied, and observations were made in 80 registered crested wheatgrass fields in many parts of Montana.

IDENTIFICATION OF SEEDS

The seeds of Standard and Fairway crested wheatgrass differed in size, shape, weight, percentage of awned seed, and enclosure of the palea by the lemma. When these differences were considered, it was possible to make reliable identifications and approximate separations of mixtures. Percentages given refer to the proportion of the seed examined.

1. Size
   - Length in millimeters not including the awn
     - Standard: More than 6 mm, 68%; 6 mm, 28%; and less than 6 mm, 4%.
     - Fairway: More than 6 mm, 6%; 6 mm, 56%; and less than 6 mm, 38%.
   - Average width in millimeters
     - Standard: 1.00
     - Fairway: 0.75

   Observations have shown that seeds grown under adverse conditions, or from certain cleaning separations, may be somewhat reduced in length. However, under such circumstances, Standard seeds maintained a greater width and it was usually possible to distinguish between the two strains by careful observations.
2. Awns
   - Presence on seeds
     - Standard: Present on 14 to 55%, average 30%.
     - Fairway: Present on 50 to 88%, average 70%.

[1]Contribution from Montana State College, Agricultural Experiment Station, Bozeman, Mont. Paper No. 123, Journal Series. Received for publication March 20, 1939.

[2]Seed Analyst.

Length of awns in millimeters

Standard: Less than 0.5 mm to more than 4.0 mm, average 2.0 mm.

Fairway: Range from 2.5 mm to 4.0 mm, average 3.0 mm.

In threshing, the awns of the Standard strain tended to break off entirely or partially more easily than those of Fairway. This difference in the percentage of awned seeds and length of awns was strikingly apparent when samples of the two strains were compared.

3. Shape

Standard: 70% tapering

Fairway: 72% boat-shaped

This difference was not clearly defined but was of assistance in making analytical separations of the two strains.

4. Enclosure of palea

Standard: Lemmas fitted closely over edges of palea almost covering veins on which the teeth occurred in 72% of the seed.

Fairway: Lemma rarely extended to toothed palea veins except in immature seed.

This difference was not always pronounced but in connection with other characters was of assistance in identifying certain seeds. A hand lens or microscope was necessary for this determination.

5. Weight

Standard: Average weight of 1,000 seeds was 2.41 grams.

Fairway: Average weight of 1,000 seeds was 1.38 grams.

One thousand seeds of the heaviest Fairway sample weighed 1.56 grams. This was 0.16 gram less than 1,000 seeds of the lightest standard sample taken from a lot of screenings. The difference in the weight of Standard and Fairway seeds was normally a reliable means of distinguishing between the two strains. The differences between the seeds of the two strains are shown in Fig. 1.

IDENTIFICATION OF PLANTS

Plants of the two strains were studied in the seedling stage and during the period from heading to maturity. The important differences observed were as follows:

I. Seedling stage (percentages refer to the proportion of the plants examined)

1. Upper surface of leaves

Standard: Fine leaf-hairs usually thinly scattered, 24% of plants. Remainder glabrous.

Fairway: Fine leaf-hairs found on 100% of plants. Thinly scattered on some plants.

2. Auricles

Standard: Present on 46%.

Fairway: Present on 84%.

The auricles varied from clawed to wanting but were generally more prominent and longer on the Fairway. Auricles tended to dry up and break off as the plants approached maturity. This character, therefore, was not reliable after the leaf sheath edges began to dry up.

3. Leaf-sheath spines
   Standard: Present at sides of collar or along edge of leaf-sheath on 81% of plants.
   Fairway: Not present.

These coarse hairs or spines tended to drop off as the plants approached maturity but were a better character for identification than the auricles.

The seedling studies were made on plants grown in the greenhouse. Plant height measurements and leaf counts were made at 3-day intervals for 42 days after emergence. During this period little difference was observed in the height and in the number of leaves per plant Stems were cut from the greenhouse plants for binocular microscope observation 65 days after planting. At this stage the plants had begun to stool, having two or more stems and six or more leaves per plant. The differences in seedling characters are illustrated in Fig. 2.

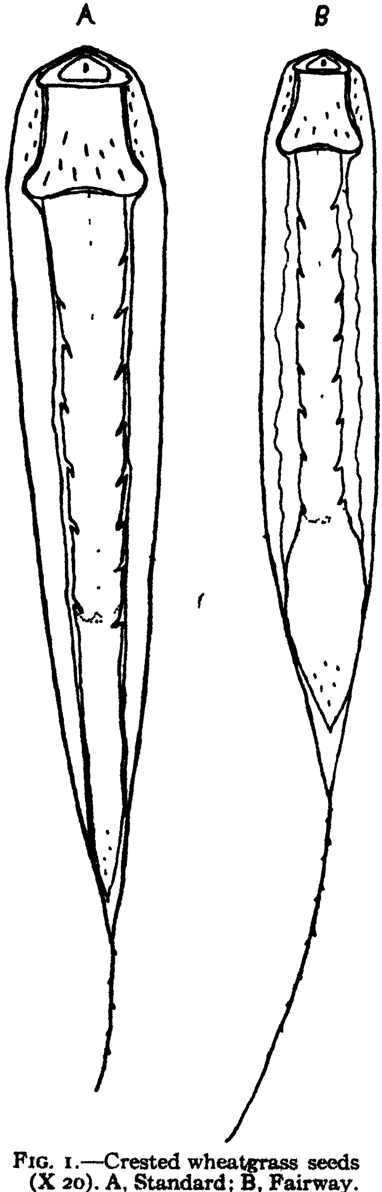

FIG. 1.—Crested wheatgrass seeds (X 20). A, Standard; B, Fairway. Differences in size, shape, awns, and enclosure of the seed by the lemma are shown.

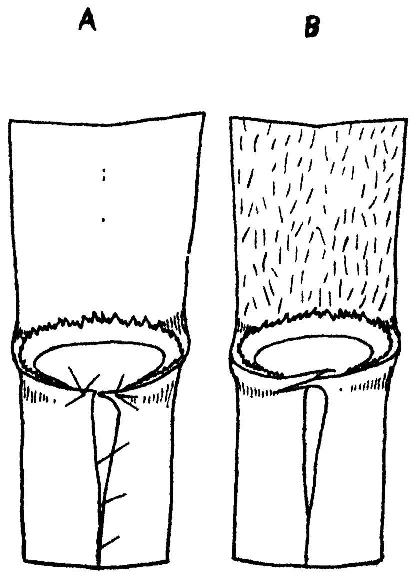

FIG. 2.—Crested wheatgrass ligule area (X 10). A, Standard; B, Fairway. Fine hairs on upper leaf surface of Fairway and coarse hairs on leaf sheath of Standard are shown.

II. Headed plants

1. Variability in height and coarseness
   Standard: Stems varied greatly in height, coarseness, and number per plant (Fig. 3).
   Fairway: Stems more uniform in height and number. Usually finer, more stems per plant and medium height.
2. Color
   Standard: Plants varied from dark green to grayish green.
   Fairway: Plants usually bright green.

FIG. 3.—Showing variation in growth of individual plants of the Standard strain.

3. Spikes
   Standard. Variable; tapering or cylindrical, twisted or straight, erect or nodding, large or small (Fig. 4).
   Fairway: Broad at base and tapering toward tip.
4. Awns
   Standard: Varied in length from less than 0 5 mm to more than 5.0 mm. Some spikes were awnless.
   Fairway: Usually longer than on standard and less variable. Average 3.0 mm in length.
5. Upper surface of leaves
   Standard: Hairs present on but few plants, usually thinly scattered.

Fairway: Long, fine hairs present on practically all plants. In the field the best time to observe the above differences in the headed plants was shortly before the bloom stage when the variability of the Standard strain was more pronounced.

FIG. 4.—Head types of crested wheatgrass A and B, Fairway strain; remainder Standard strain.

Fairway being a selection was less variable in all characters. Hairs on the upper leaf surface were best seen in the field by rolling the leaf over the finger and holding it toward the sun. As the plants approached maturity, distinction between the two strains became more difficult.

SUMMARY

Seeds and plants of Standard and Fairway crested wheatgrass were examined to determine the differences which would furnish a means of more definitely identifying these two strains

The differences in size, weight, shape, percentage of awned seeds, and enclosure of the palea by the lemma made it possible to distinguish the two strains and determine the approximate percentage of each in mixtures of seed

Identification was most difficult in the seedling stage but plantings of the two pure strains were identified by the presence or absence of leaf-hairs, hairs on the leaf sheath edges, and auricles

Field plantings of the two strains were most easily distinguished just before blooming At that stage of growth, the differences in the size and shape of the spikes and the variations in the height and color of standard plants were most pronounced as contrasted with the greater uniformity of Fairway. These variations furnished the best means of distinguishing between the two strains in the field.

THE EFFECT OF CULTIVATION AND EROSION ON THE NITROGEN AND CARBON OF SOME KANSAS SOILS[1]

J. C. Hide and W. H. Metzger[2]

HORIZONTAL or contour cultivation was recognized in the United States as a desirable practice for erosion control by Randolph, and advocated by Jefferson, before the year 1800. This method of cultivation has not been generally used by farmers, and until very recently was not extensively advocated by agricultural specialists. Experimental field work on the desirability of the practice is of recent origin.

EXPERIMENTAL PROCEDURE

In an effort to compare cultivation across the slope with up and down hill cultivation in regard to loss of carbon and nitrogen, 20 sets of samples were taken from farmers' fields in the eastern half of Kansas Each site is represented by three samples, the first of which was located on sod land which, in so far as could be determined, had never been cultivated. The two additional samples were taken from an adjacent cultivated field of similar slope, one where the cultivation marks were directed up and down and the other where the cultivation has been approximately across the slope. These samples were mostly taken from fields of such dimension or location that past cultivation has been predominantly in one direction. Locations representing across the slope cultivation were selected only by observation and have very probably suffered greater erosion losses than would have been the case with carefully contour cultivated land.

With the exception of sites 18 and 20, which are located at the extreme eastern edge of the chernozem belt, all of the soils sampled belong to the Prairie group. In texture the soils are mostly silt loams or silty clay loams, but very fine sandy loams are found at sites 1, 2, 4, and 15 The exact period of cultivation could not be determined, but by statements obtained from farmers it was found that, with two or three exceptions, the cultural period was at least 30 years, and in many cases was much longer. Settlement in the eastern part of the state started about 1855 and in the central area was about 10 years later.

At each site a 0- to 7-inch surface sample and a 7- to 20-inch subsurface sample were taken. The samples were collected in cardboard cartons, brought to the laboratory, air dried, and stored until the following winter when the analyses were made. The samples from northeast and north central Kansas were taken in 1936, and those for southeast and south central Kansas in 1937.

Organic carbon and total nitrogen determinations were made on each sample. The organic carbon was determined by the method of Schollenberger as outlined by Allison (1).[3] For the nitrogen determination the samples were digested according to the Gunning-Hibbard procedure, distilled into 4% boric acid, and titrated with N/7 H_2SO_4 in the presence of brom-cresol-green and methyl red. The data obtained are presented in Tables 1 and 2 and are shown graphically in Fig. 1.

[1]Contribution No. 293 from the Agronomy Department of the Kansas Agricultural Experiment Station, Manhattan, Kan. Received for publication March 20, 1939.

[2]Assistant Professor of Soils and Associate Professor of Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 632.

Data covering samples from approximately one-half of the state and representing 13 soil series, 18 soil types, and different rainfall conditions would be expected to be highly variable. However, the variability does not conceal some very definite trends in the data.

LOSS OF CARBON AND NITROGEN DUE TO CULTIVATION

A comparison of the data in column 2 with that in column 4 of Tables 1 and 2 or an examination of Fig. 1 show a very evident decrease in carbon as a result of cultivation and cropping. Columns 3 and 5 show a similar reduction in nitrogen resulting from the same treatment. The average of the data for the 20 sites shows a loss of 37% of the carbon and 32% of the nitrogen from the surface soil, while the loss from the subsurface soil was, respectively, 25 and 20%. In 19 of the cases the carbon and nitrogen in both the surface and subsurface soil have decreased as a result of cultivation. The exception is probably due to sampling error. Statistical treatment shows this loss to be highly significant.

The nitrogen loss has been relatively less than the carbon loss. In 17 of the cases in both the surface and subsurface, the carbon-nitrogen ratio has decreased as a result of cultivation. This is in agreement with the frequent observation that as the decomposition of organic matter proceeds, the carbon-nitrogen ratio becomes narrower.

Under conditions at three experimental fields in western Kansas very large losses of nitrogen were found by Gainey, Sewell, and Latshaw (2) to result from cultivation and cropping. The amount of this loss was largely dependent on the amount of nitrogen originally present in the soil. When the data of Table 1 are divided into two groups according to nitrogen content, greater absolute loss from the higher nitrogen group is found, the nitrogen decreasing from an average of 0.217% to 0.145% while for the lower group the decrease was from an average of 0.152 to 0.104%. However, the percentage loss remains about constant, being 33.2 for the upper group and 31.3 for the lower group.

A "cultivation factor" was established by expressing the carbon in the sample cultivated across the slope as percentage of the carbon in the sod sample. This represents the relative amount of carbon which was retained following the cultural treatments in use on the farm when erosion was at least partially controlled. These data are given in column 8 of Tables 1 and 2, and show a very interesting relationship between the carbon loss and the amount of annual rainfall, the loss becoming greater as the rainfall decreases. This relationship is shown distinctly in Fig. 2 where the "cultivation factor" for the surface soil is plotted against the rainfall. The correlation coefficient for these data is .5737, giving odds for significance of slightly greater than 99 to 1. In the subsoil data the correlation coefficient is .2594, giving odds for significance of only about 7 to 1.

The data are not sufficiently extensive and do not cover a wide enough rainfall area to establish the exact nature of the curve. Yet, averages of the groups of samples shown in Fig. 2 fall close to a straight line. Sewell and Gainey (5) found that under cultivation a

TABLE 1.—*Carbon, nitrogen, and related data for the surface soil.*

Sample No.	Sod C, %	Sod N, %	Across slope C, %	Across slope N, %	Up and down slope C, %	Up and down slope N, %	Cultivation factor,* %	Conservation factor,† %	Rainfall, inches	Slope	Country
					Southeast Kansas						
1	1.21	0.094	0.93	0.077	0.79	0.068	76.9	84.9	40.12	3.7	Labette
2	1.96	0.142	1.13	0.092	0.77	0.066	57.7	68.1	40.12	2.5	Labette
3	3.16	0.226	3.02	0.222	2.51	0.186	95.6	83.1	38.08	1.5	Allen
4	2.34	0.172	1.34	0.100	1.29	0.104	57.3	96.3	37.71	2.3	Montgomery
5	2.24	0.170	2.39	0.181	1.94	0.160	106.7	81.2	36.41	3.5	Franklin
Av.	2.18	0.161	1.76	0.134	1.46	0.117	78.8	82.7	38.49	2.7	
Rel.‡	100	100	80.7	83.2	67.0	72.7	—	—	—	—	
					Northeast Kansas						
6	2.36	0.185	1.57	0.119	1.39	0.117	66.5	88.5	36.34	8.0	Jackson
7	2.97	0.214	2.40	0.178	1.91	0.155	80.8	79.6	35.50	8.0	Leavenworth
8	2.91	0.222	2.15	0.165	1.54	0.127	73.9	71.6	35.50	8.0	Leavenworth
9	1.98	0.156	0.73	0.073	0.52	0.057	36.9	71.2	34.29	25.0	Doniphan
10	3.05	0.242	1.57	0.140	1.39	0.127	51.5	88.5	33.81	10.0	Doniphan
Av	2.65	0.204	1.68	0.135	1.35	0.117	61.9	79.9	35.09	—	
Rel	100	100	63.4	66.2	50.9	57.4	—	—	—	—	
					South Central Kansas						
11	1.90	0.141	1.17	0.096	1.12	0.094	61.6	95.7	33.42	2.9	Cowley
12	2.19	0.153	1.42	0.119	1.06	0.091	64.8	74.6	33.42	2.1	Cowley
13	3.21	0.236	2.27	0.158	2.06	0.163	70.7	90.7	31.37	3.4	Marion
14	3.31	0.225	1.90	0.145	2.57	0.188	57.4	135.3	31.37	4.0	Marion
Av.	2.65	0.189	1.69	0.130	1.70	0.134	63.6	99.1	32.40	—	
Rel.	100	100	63.8	68.8	64.2	70.8	—	—	—	—	
					North Central Kansas						
15	1.80	0.139	1.16	0.097	0.98	0.087	64.4	84.5	29.54	15.0	Washington
16	2.96	0.227	1.37	0.119	1.27	0.099	46.3	92.7	28.31	5.0	Clay
17	2.26	0.177	1.13	0.100	1.25	0.118	50.0	110.6	28.31	7.0	Clay
18	2.19	0.172	1.05	0.107	0.67	0.074	47.1	63.8	24.97	12.0	Jewell
19	2.73	0.209	0.96	0.097	0.94	0.093	35.2	97.9	24.97	7.0	Jewell
20	2.37	0.186	1.26	0.112	1.53	0.138	53.2	121.4	24.97	5.0	Jewell
Av.	2.39	0.185	1.16	0.105	1.11	0.102	49.4	95.2	26.84	—	
Rel.	100	100	48.5	56.8	46.4	55.1	—	—	—	—	
					Average						
Av.	2.46	0.184	1.55	0.125	1.37	0.116	62.7	89.0	—	—	
Rel.	100	100	63.3	68.0	55.9	63.0	—	—	—	—	

*Carbon for the site cultivated across the slope expressed as a percentage of the carbon in the sod sample.
†Carbon for the site cultivated up and down the slope expressed as a percentage of the carbon in the sample cultivated across the slope.
‡Carbon or nitrogen expressed as percentage of the amount in the sod sample.

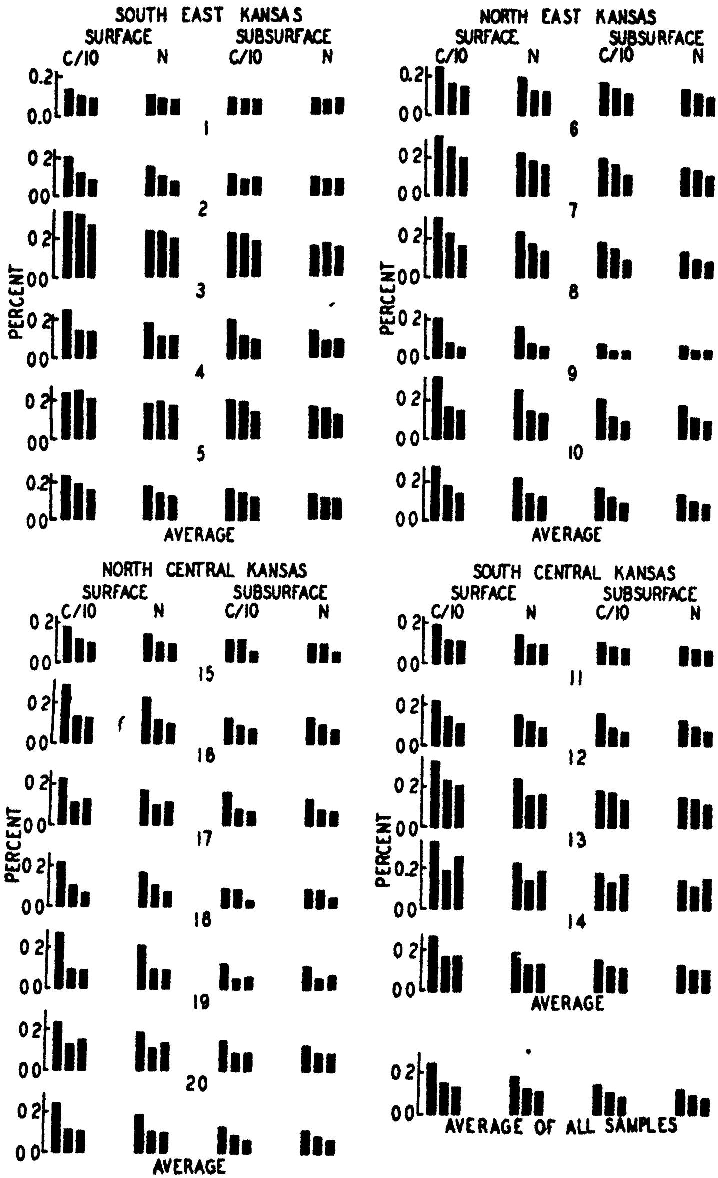

FIG. 1.—Carbon and nitrogen content of soil under sod and of similar soils differently cultivated. In each group of three, the left bar represents sod land, the center bar land cultivated across the slope, and the right bar land cultivated up and down the slope. For convenience in presentation the carbon data have been divided by 10.

soil at Colby where the annual rainfall is 18.4 inches lost 60% of its carbon in 23 years, a soil at Garden City under 20.2-inch rainfall lost 39.5% in 20 years, and one at Hays under rainfall of 23.7 inches lost 54.5% in 26 years. These soils also differ somewhat in texture, the Garden City soil being somewhat coarser than that at Colby or Hays. These losses are of about the same order as those obtained by the authors for samples taken in Jewell County under 25-inch rainfall. This may indicate a leveling of the line in that portion represented

TABLE 2.—*Carbon and nitrogen data for the subsurface soil.*

Sample No.	Sod		Across slope		Up and down slope		Cultivation factor,* %	Conservation factor,† %
	C, %	N, %	C, %	N, %	C, %	N, %		
				Southeast Kansas				
1	0.80	0.075	0.70	0.066	0.75	0.072	87.5	107.1
2	1.03	0.086	0.76	0.068	0.87	0.078	73.8	114.5
3	2.12	0.150	2.08	0.168	1.72	0.144	98.1	82.7
4	1.82	0.134	1.01	0.090	0.89	0.095	55.5	88.1
5	1.88	0.158	1.80	0.148	1.26	0.114	95.7	70.0
Av	1.53	0.121	1.27	0.108	1.10	0.101	82.1	92.5
Rel.‡	100	100	83.0	89.0	71.9	83.5	—	—
				Northeast Kansas				
6	1.62	0.128	1.31	0.105	1.01	0.091	80.9	77.1
7	1.93	0.143	1.59	0.132	1.03	0.102	82.4	64.8
8	1.73	0.134	1.41	0.094	0.82	0.080	81.5	58.2
9	0.68	0.066	0.35	0.041	0.35	0.043	51.5	100.0
10	1.99	0.169	1.15	0.108	0.94	0.089	57.8	81.7
Av.	1.59	0.128	1.16	0.096	0.83	0.081	70.8	76.4
Rel	100	100	73.0	75.0	52.2	63.3	—	—
				South Central Kansas				
11	1.07	0.091	0.86	0.077	0.79	0.069	80.4	91.9
12	1.60	0.123	0.92	0.094	0.71	0.068	57.5	77.2
13	1.81	0.152	1.77	0.142	1.39	0.117	97.8	78.5
14	1.79	0.143	1.33	0.112	1.73	0.154	74.3	130.1
Av.	1.57	0.127	1.22	0.106	1.16	0.102	77.5	94.4
Rel	100	100	77.7	83.5	73.9	80.3	—	—
				North Central Kansas				
15	1.09	0.092	1.12	0.090	0.50	0.048	102.8	44.6
16	1.28	0.129	0.92	0.098	0.74	0.071	71.9	80.4
17	1.63	0.130	0.82	0.080	0.70	0.073	50.3	85.4
18	0.96	0.091	0.88	0.087	0.35	0.046	91.7	39.8
19	1.22	0.112	0.52	0.058	0.60	0.069	42.6	115.4
20	1.49	0.123	0.88	0.092	0.91	0.091	59.1	103.4
Av.	1.28	0.113	0.86	0.084	0.63	0.066	69.7	78.2
Rel.	100	100	67.2	74.3	49.2	58.4	—	—
				Average				
Av.	1.48	0.121	1.11	0.097	0.90	0.086	74.7	84.5
Rel.	100	100	75.0	80.1	60.8	71.1	—	—

*Carbon for the site cultivated across the slope expressed as a percentage of the carbon in the sod sample.
†Carbon for the site cultivated up and down the slope expressed as a percentage of the carbon in the sample cultivated across the slope.
‡Carbon or nitrogen expressed as percentage of the amount in the sod sample.

by the samples of the lower rainfall areas or it may be that the period of cultivation at these western Kansas sites has been somewhat shorter than in Jewell County and the loss of carbon has not proceeded as far.

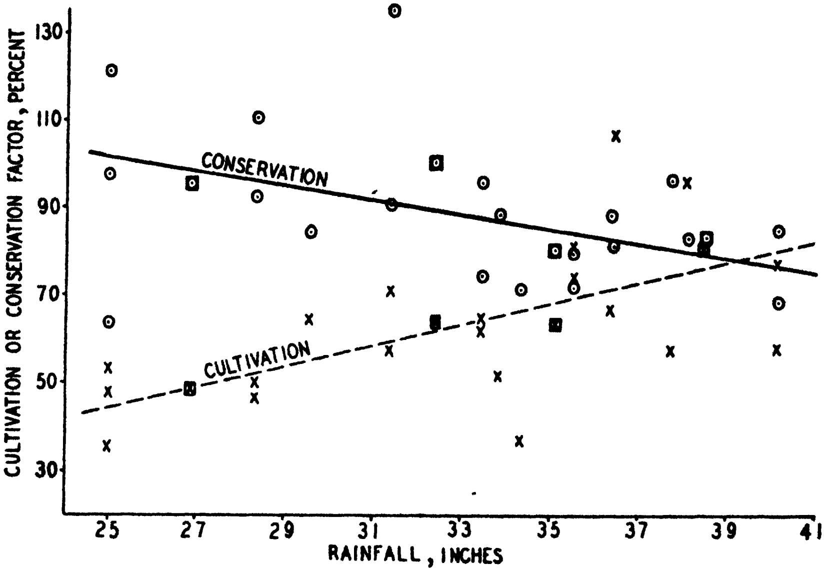

FIG. 2.—Cultivation and conservation factors in relation to rainfall. The x symbols represent "cultivation factors"; the circle and dot, "conservation factors"; and the boxed symbols group averages. The lines are drawn in from inspection of the data. (See footnotes to Table 1.)

The cultivation data at the upper end of the curve in Fig. 2 are quite variable, which may indicate that the apparent straight line relationship is starting to break down. However, support for the idea that a rise may continue with increasing rainfall is provided by Wheeting (6) who finds an increase in the carbon content of the humid forest soils of western Washington following cultivation and cropping. His data are not directly applicable to eastern Kansas conditions since it has been shown by Jenny (3) that organic matter relationships in the soil are dependent on at least temperature and moisture.

LOSS OF CARBON AND NITROGEN DUE TO EROSION

An examination of Tables 1 and 2 and of Fig. 1 shows that a greater loss of carbon and nitrogen has occurred from the sites where cultivation was directed up and down the slope than where it was across the slope. This loss is attributed entirely to erosion and, while it is not the total erosion loss, it is a loss that could readily have been prevented by proper cultural treatment. It should again be pointed out that the samples representing across the slope cultivation were selected only by observation and the data are consequently a very conservative approximation of the results that could be obtained with careful contour cultivation.

A comparison of the data in column 4 with those in column 6 of the tables shows that cultivation across the slope when compared with cultivation up and down the slope has maintained more carbon in the surface soil in 17 of the 20 cases and in the subsoil in 15 cases. The nitrogen loss due to erosion has been slightly less than the carbon loss. The average of all of the data for the surface soils shows that cultivation across the slope when compared with sod land has maintained 63.3% of the carbon while up and down the slope cultivation maintained only 55.9%. If the eastern Kansas data only are considered the percentages are, respectively, 71.1 and 57.8. For the 20 sites, cultivation across the slope conserved 16.8% of the carbon that was lost when cultivation was directed up and down the slope while in eastern Kansas it conserved 31.5%. A similar conservation can be observed from the subsoil data. Calculation of the Z value according to Love and Brunson (4) and use of Love's tables show odds of 65 to 1 for significance of the carbon loss due to erosion from the surface soil, while in the subsoil the odds for significance are 430 to 1.

A "conservation factor" was established by expressing the carbon in the samples taken where the cultivation had been directed up and down the slope as a percentage of that in the samples from land which had been cultivated across the slope. According to this concept, when the carbon content equals that of the sample taken where cultivation was across the slope, conservation is considered to be 100%. These data are given in column 9 of Tables 1 and 2. From the group averages it is apparent that the erosion loss has been greater from the two eastern sections of the state than from the two central sections The data for the central sections are highly variable and though the averages show practically no saving for contour cultivation, this is very probably a result of the data being insufficient for areas in which variability is so high. The average for south central Kansas should be questioned since three of the values are of the same order and show an average "conservation factor" of 87 which is offset by the data at site 14 where the two cultivated samples were taken at a considerable distance apart.

In Fig. 2 the "conservation factor" for the surface soil is plotted against rainfall and indicates a possible inverse relationship, the percentage of carbon conserved increasing as the rainfall decreases. These data, however, yield a correlation coefficient of only —.4003 giving odds of slightly less than 19 to 1 while the subsoil data give a coefficient of +.1235.

Throughout the area studied, the rainfall comes mostly during the growing season and much of it in the form of downpours.

SUMMARY

At each of 20 sites in the eastern half of Kansas soil samples were taken to represent sod land, land which has been cultivated across the slope, and land which has been cultivated up and down the slope. Organic carbon and total nitrogen determinations were made on these samples.

In comparison with the sod sample, cultivation across the slope associated with cropping has brought about a highly significant loss

of carbon and nitrogen amounting to 37 and 32%, respectively, for the surface 7 inches of soil, and 25 and 20% in the 7- to 20-inch layer. The actual loss of carbon becomes significantly greater as the average annual rainfall decreases from 40 inches in southeast Kansas to 25 inches in north central Kansas.

The carbon loss which occurred from the surface soil where the land has been cultivated across the slope is 16.8% less than where cultivation has been up and down the slope. This saving is statistically significant. If only that half of the data from the relatively humid extreme eastern section of the state is considered, the carbon loss was reduced 31.5% by cultivation across the slope.

LITERATURE CITED

1. ALLISON, L. E. Organic soil carbon by reduction of chromic acid. Soil Sci., 40:311–320. 1935.
2. GAINEY, P. L., SEWELL, M. C., and LATSHAW, W. L. The nitrogen balance in cultivated semi-arid western Kansas soils. Jour. Amer. Soc. Agron., 21:1130–1153. 1929.
3. JENNY, HANS. A study of the influence of climate upon the nitrogen and organic matter content of the soil. Mo. Agr. Exp. Sta. Res. Bul. 152. 1930.
4. LOVE, H. H., and BRUNSON, A. M. Student's method for interpreting paired experiments. Jour. Amer. Soc. Agron., 16:60-68. 1924.
5. SEWELL, M. C., and GAINEY, P. L. Organic matter changes in dry farming regions. Jour. Amer. Soc. Agron., 24:275-283. 1932.
6. WHEETING, L. C. Changes in organic matter in western Washington soils as a result of cropping. Soil Sci., 44:139-150. 1937.

BURIED RED RICE SEED[1]

W. L. Goss and Edgar Brown[2]

RED rice is the most troublesome weed pest occurring in rice fields. Once harvested with the cultivated rice crop, it cannot be removed by any known machinery. The kernel is often slightly smaller than that of commercial rice varieties and the red seed coat from which it derives its name cannot be entirely removed in the milling process without materially reducing the yield of head rice. Streaks of the red bran which often are left on the milled kernels seriously injure the appearance of the milled rice and lower the grade.

A survey of seed rice used in the states of Louisiana, Texas, and Arkansas was made in the spring of 1929 by W. D. Smith, J. J. Deffes, and C. H. Bennett of the Rice Project, Grain Investigations, Grain Division, Bureau of Agricultural Economics, U S. Dept. of Agriculture. They drew samples from 337 lots of rice seed actually being planted Of these samples, 54% contained seeds of red rice, the average number per pound being 28 One sample showed 585 red rice per pound Using 80 pounds per acre, over half of the rice growers were planting on an average about 2,300 red rice seeds per acre or 1 on every 18 square feet

A similar survey was made in California by the Federal-State Seed Laboratory in the spring of 1932. Samples were obtained from the seed being used in planting approximately one-sixth of the state's rice acreage. Of the samples taken, 42% contained red rice seed ranging from 3 to 57 seeds per pound. The California Federal-State rice inspection service reported in 1932 that of 907,251 sacks of rough rice inspected, 2.9% graded No. 2, 1.9% graded No. 3, 3.2% graded No. 4, and 0.3% graded No. 5 because of red rice.

Red rice is known to volunteer in the rice fields of the South, but just how long the seeds are capable of remaining viable in the soil is not definitely known.

An experiment was planned by the U. S. Dept. of Agriculture to determine the length of time red rice seed will remain viable in the soil under different climatic conditions and was started in the fall of 1930.

PLAN OF EXPERIMENT

Five samples of red and two samples of cultivated white rice were buried on the rice experiment stations at Stuttgart, Ark., October 28, 1930, at Beaumont, Tex., October 31, 1930, and at Biggs, Calif., November 17, 1930. At each station, 12 pits were dug, 6 so located that they would be submerged as is practiced in growing a normal crop of rice, and 6 so located that they would receive natural rainfall only.

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[1]Contribution from the U. S. Dept. of Agriculture, Washington, D. C., in cooperation with the State Department of Agriculture, Sacramento, Calif. Received for publication March 20, 1939.

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The seed was buried as follows: 200 seeds were mixed with enough dry soil to fill a 4-inch flower pot about three-quarters full. The mixture of the seed and soil was then pressed firmly into the pots and the remaining space filled with dry soil and then covered with a porous clay saucer. The pot and saucer were then inverted and placed in the pit, which was dug deep enough to allow for a 4-inch soil cover. The soil was packed firmly about the pots. The porous nature of the pots allows free circulation of moisture through the soil in the pots. The object was to subject the seeds, as nearly as possible, to the conditions which would prevail if they were plowed under and to be able to reclaim them for periodic germination tests. Seven pots, each containing a different sample of seed, were placed in each pit. It was planned to take up the seven pots from one of the dry and one of the wet pits at each of the three stations and test the seeds for germination in 1931, 1932, 1933, 1935, 1937, and 1940.

At Biggs, envelopes containing seed from each lot were placed in quart glass easy-seal jars, sealed as in canning fruit, and buried bottom-side up in each pit of the dry plot. In the irrigated plot at Biggs there was buried in each pit an unmarked pot containing seeds of water plantain (*Alisma plantago*) and water grass (*Echinochloa crusgalli*). Both the water plantain and the water grass have produced some sprouts each year that they have been tested previous to 1937, but the percentage of growth has been low, perhaps due to unfavorable conditions for germination. Weed seeds are often difficult to germinate under laboratory conditions.

Sets from the irrigated and non-irrigated plots were taken up and tested for germination in the spring of 1931, 1932, 1933, 1935, and 1937.

RESULTS

Table 1 shows the germination results obtained from the seeds buried in actual contact with the soil at the three stations for each of the years in which they have been taken up and tested for germination.

From these results, it is evident that the southern red rices retain their vitality when buried in the soil much longer than does either the Italian or California red or the cultivated white rices. It also appears that the southern reds retain their viability longer under Texas and Arkansas conditions than under California conditions. Under Texas and Arkansas conditions, the seed buried in the irrigated plots retained its vitality longer than that in the unirrigated plots. In California, the results were practically the same for the irrigated and unirrigated plots except that the Italian purple-awned red survived much longer under dry conditions. The California white-awned red rice and the two samples of cultivated white rice gave little or no germination after the first year. The Italian purple-awned red rice from California showed more resistance and retained its viability longer in California than in either Texas or Arkansas.

Table 2 gives the germination of each lot of seed before it was buried, the germination of samples from the same lot kept in dry storage in the Seed Laboratory at Washington, D. C., and the germination of samples from the same lots after they had been buried in sealed containers protected from outside moisture but subjected to the same temperature conditions as the seed buried in the terra cotta

TABLE 1.—*Vitality of red rice seed after being buried in the ground for one, two, three, and five winters.**

Year	Beaumont, Tex.		Stuttgart, Ark.		Biggs, Cal.	
	Irrigated %	Non-irrigated %	Irrigated %	Non-irrigated %	Irrigated %	Non-irrigated %
	Italian Red Rice, Purple Awns					
1931	0.0	1.0	29.0	0.0	2.0	15.5†
1932	1.5	2.0	14.0	0.5	0.5	35.0
1933	0.5	0.0	1.5	1.5	0.5	16.5
1935	0.0	0.0	2.5	1.0	0.05	0.0
1937	0.0	0.0	0.0	0.5	0.0	0.0
	California Red Rice, White Awns					
1931	0.0	0.0	17.0	0.0	4.5	2.0
1932	0.0	0.0	4.5	2.0	1.0	0.0
1933	0.0	0.0	7.0	0.5	1.0	0.0
1935	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	3.0	0.0	0.0	0.0
	Southern Blackhull Red Rice					
1931	80.0†	47.5†	87.0	36.0†	95.0	99.0
1932	88.5	82.0	80.0	50.5	82.0	66.0
1933	80.5	59.0	47.5	31.0	7.0	1.0
1935	59.5	2.0	27.0	27.5	3.0	0.0
1937	2.5	0.0	20.0	1.5	0.0	0.0
	Southern Red Rice					
1931	58.0†	67.5	75.0	18.0†	67.5	63.5
1932	64.5	17.0†	45.0	42.5	67.0	36.5
1933	50.5	25.0	56.5	35.0	19.0	3.0
1935	7.0	0.0	11.5	0.5	6.0	0.0
1937	0.0	0.0	4.5	1.5	0.0	0.0
	Southern Red Rice					
1931	54.5	70.5	67.5†	20.0†	67.5	58.0
1932	44.0	8.5†	79.5	51.5	65.0	18.0
1933	15.5	23.0	59.0	27.5	5.5	5.0
1935	0.0	0.0	12.0	7.0	6.0	0.0
1937	0.0	0.5	2.5	1.0	0.5	0.0
	Supreme Blue Rose Rice					
1931	2.0	0.0	23.5	0.0	0.5	6.0
1932	0.0	0.0	0.0	0.0	0.0	0.0
1933	0.0	0.0	0.0	0.0	0.0	0.0
1935	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	0.0	0.0	0.0	0.0
	Caloro Rice					
1931	1.0	0.5	18.0	0.0	9.0	8.5
1932	0.0	0.0	0.0	0.0	1.0	0.0
1933	0.0	0.0	0.0	0.0	0.0	0.0
1935	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	0.0	0.0	0.0	0.0

*The germination tests of the seed buried at Biggs, Cal., were made at the California Cooperative Seed Testing Laboratory, Sacramento, Cal., and the tests of those buried at Beaumont, Tex., and Stuttgart, Ark., were made at the Division of Seed Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

†These apparent low percentages were due to germination having occurred before the seed reached Washington, D. C., and the percentage could not be determined. The percentages show only germination after receipt.

pots. No test was made of the laboratory stored seed after 1933. The seed buried in the glass jar at Biggs retained its vitality perfectly for 2 years and only the two samples of cultivated rice showed serious loss of germination the third year. The rubber seal on the

TABLE 2.—*Germination of original red rice seed and of seed in dry storage in the laboratory and in sealed containers buried in the field.*

Year tested	Germination		
	At time of storage, %	Laboratory storage at Washington, D. C., %	Sealed container, non-irrigated plot, Biggs, Calif., %
	Italian Red Rice, Purple Awns		
1930	97.0		
1931		98.50	97.00
1932		99.00	96.50
1933		90.00	95.50
	California Red Rice, White Awns		
1930	93.00		
1931		97.50	97.00
1932		92.00	97.50
1933		85.50	83.50
	Southern Red Rice, Blackhull		
1930	76.00*		
1931		97.00	92.00
1932		97.50	100.00
1933		93.00	85.00
	Southern Red Rice		
1930	82.00*		
1931		94.00	88.00
1932		88.00	90.00
1933		82.50	84.50
	Southern Red Rice		
1930	83.00*		
1931		90.50	86.00
1932		86.00	88.50
1933		85.00	88.50
	Supreme Blue Rose Rice		
1930	86.50		
1931		92.50	94.00
1932		83.50	85.00
1933		74.50	62.50
	Caloro Rice		
1930	93.50		
1931		94.00	94.00
1932		81.50	88.50
1933		45.00	10.50

*Apparently seed was dormant when original test was made.

glass jar failed before the seeds were taken up in 1935, admitting moisture and consequently spoiling the seed, making a germination test useless.

CONCLUSIONS

Under dry storage at soil temperature conditions existing in California, all of the red rices tested showed good vitality after three winters. The cultivated rices showed loss of vitality in the third year, especially the Caloro variety.

Cultivated white rice when buried in the soil at the depth of ordinary plowing loses its vitality during the first winter.

Italian and California red rices behave very similarly to cultivated rices although they are slightly more persistent.

In general, the seed remained alive longer in the irrigated than in the non-irrigated plots.

The Italian purple-awned red variety retains its vitality longer than the California white-awned, particularly under dry conditions.

The southern red rices show good vitality after 3 years in the soil and some germination after 7 years. They appear to persist longer under Texas and Arkansas conditions than under California conditions.

It is evident that clean culture during a short rotation will not rid the land of red rice.

THE EFFECT OF CARBON DIOXIDE PRESSURE UPON EQUILIBRIUM OF THE SYSTEM HYDROGEN COLLOIDAL CLAY-H_2O-$CaCO_3$[1]

CHARLES F. SIMMONS[2]

THE reaction between $CaCO_3$ and soils is one of the most important in soil chemistry. As a result it has been investigated under a wide range of conditions by a very large number of workers. In the great majority of these studies, however, factors known to have an appreciable effect upon the reaction were not adequately controlled. The pressure of CO_2 above the reacting system is one of the most important of these factors. The carbon dioxide content of the soil air is known to vary from 0.03 to 12.0% largely as a result of variations in biological activity and soil ventilation. It is well known that CO_2 dissolves in water to form carbonic acid. The effect of the pressure of CO_2 upon the amount absorbed by water and various salt solutions has been thoroughly investigated. The data of Bohr (3)[3] are commonly regarded as quite reliable. Water charged with CO_2 is known to be a good solvent for many soil minerals, especially calcite. The effect of CO_2 pressure upon the solubility of calcite in water has been investigated (8) and later reinvestigated by Johnston and his students. Frear and Johnston (5) give values obtained by plotting the best existing data.

It has been commonly assumed (4) that the amount of $Ca(HCO_3)_2$ in solution in a soil suspension containing an excess of soil $CaCO_3$ is the same as it would be if the soil were not present. If this is true and the amount of water present and the pressure of CO_2 is known, it should be possible to calculate the amount of Ca present as $Ca(HCO_3)_2$ and the amount of dissolved CO_2 in soil-$CaCO_3$-H_2O systems from the data of Frear and Johnston (5) and Bohr (3), respectively. Some of the data obtained in the course of this investigation tend to throw doubt on the strict validity of the above assumption, but a discussion of this point will be reserved until later.

Jensen (7) studied the amount of Ca fixed by soils from $CaCO_3$ at the pressure of CO_2 existing in the atmosphere by means of serial experiments in which a series of soil samples was treated with regular increments of $Ca(OH)_2$. They were then aerated until equilibrium with the air was obtained. Constancy of the pH value as measured with the quinhydrone electrode was used as the criterion for reaching equilibrium. Buffer curves obtained by plotting the pH values thus obtained against the increments of $Ca(OH)_2$ added were used to characterize the acidity of various soils.

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[3]Reference by numbers in parenthesis is to "Literature Cited", p. 648.

Bradfield and Allison (4), in an effort to find a more exact way of characterizing a soil "saturated with bases", studied various soil-$CaCO_3$-H_2O systems at the pressure of CO_2 of the atmosphere. The amount of Ca reacting with the soil was determined by analyzing the equilibrated samples for total CO_2, care being taken not to oxidize any of the organic matter of the soil. Since the total amount of $Ca(OH)_2$ added and the solubility of $Ca(HCO_3)_2$ and CO_2 were known, the amount of Ca fixed by the clay could be readily calculated. The amount fixed was found to be independent of the amount of $Ca(OH)_2$ added provided a sufficient excess was present to give some solid $CaCO_3$ after equilibration. This fact is a strong argument in favor of this concept of a base-saturated soil. The practical utility of this concept would be influenced by the sensitivity of the equilibrium to such changes in CO_2 pressure as are known to occur naturally in the soil.

Practically all the cations fixed by clay in the range of pH values involved in this study (6.5 to 8.5) are held in exchangeable form. The laws which have been found to apply to the cation exchange reactions of clays and permutits by Wiegner (11) and his students, especially Jenny (6), would be expected to apply here. These studies show that the amount of a cation absorbed by the clay depends upon: (a) The specific absorbability of the ion, which, in turn, depends upon its valance and ionic radius, and (b) the concentration of the cation at which equilibrium has been established. The empirical Freundlich adsorption isotherm applies with fair accuracy to these systems. Adsorption isotherms show that the H ion is much more strongly adsorbed by clays than is the Ca ion at similar concentrations.

In the present study H^+ and Ca^{++} are the only cations involved. They may be considered as competing with each other for a place on the clay particles. The excess of solid $CaCO_3$ always present in these experiments furnishes an inexhaustible reserve of Ca ions. The increasing quantities of CO_2 dissolving at the higher CO_2 pressures tend to increase the concentration of the H ions. The concentration of both Ca^{++} and H^+ ions will increase then as the CO_2 pressure is increased. The increases in the concentration of both ions to be expected from the investigations of Frear and Johnston (5) on the system $CaCO_3$-H_2O-CO_2 are shown in Figs. 1 and 2. It is obvious from these graphs that at the higher CO_2 pressure the H-ion concentration will increase more rapidly relatively than will the Ca-ion concentration. This fact when coupled with the known greater specific absorbability of the H ion would lead us to expect that the amount of Ca fixed by the clay would decrease as the CO_2 pressure is increased. The available data, however, are insufficient to enable one to calculate the magnitude of the decrease in any specific case.

The object of the present investigation is to determine the amount of Ca fixed by a hydrogen colloidal clay when it is treated with a known excess of $CaCO_3$ and then brought into equilibrium with various controlled pressures of CO_2, temperature being kept constant to within 0.1°C.

Expansion of this study to include some of the common soils is very desirable, but must be delayed until a complete study is made of the pure clay system. Individual studies of the bases found in the soil as well as the probable influence of the soil acids should be made.

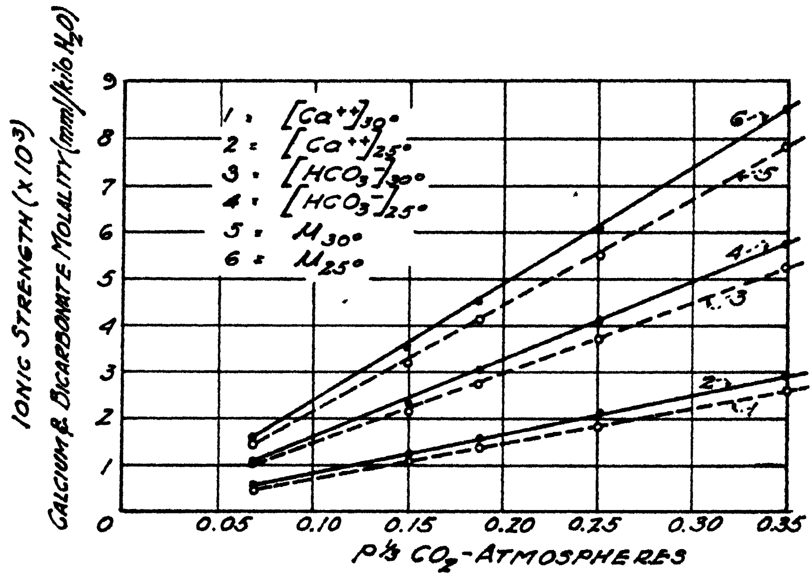

FIG. 1.—Effect of CO_2 pressure on the solubility of calcite in water.

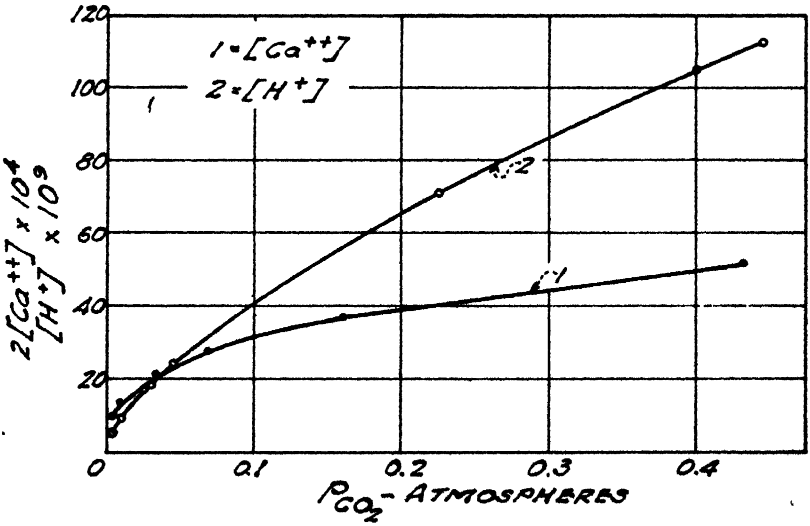

FIG. 2.—Effect of CO_2 pressure on Ca- and H-ion concentrations in aqueous solutions of calcite.

EXPERIMENTAL

PREPARATION OF MATERIALS

The colloidal clay used in this study was prepared from a Miami clay subsoil. It was dispersed with Na_2CO_3, centrifuged, and flocculated with HCl. After concentrating by centrifuging, the clay was electro-dialyzed to remove bases and

acids. Before being used it was oven dried at 105° C and then ground in an agate mortar. Because of the extreme difficulty of redispersing the colloidal clay after it had been dried, it is believed that the organic solvent method used by Truog and his students (10) would have been of considerable aid in this study.

The $Ca(OH)_2$ solution was prepared by the usual method from Merck's Blue Label CaO. The CaO was prepared by calcining C.P. $CaCO_3$ at 1050° C. The CO_2 used was a commercial grade, analyzing more than 99.9 per cent pure.

TIME REQUIRED TO REACH EQUILIBRIUM IN THE $CaCO_3$ SYSTEMS

CO_2 at 71.43 cm pressure was bubbled through 75 cc of 0.0361 N $Ca(OH)_2$ at 28.5° C to learn something of the time required for equilibrium in this system. The work of Bohr (3) shows that from 4 to 6 hours were necessary for equilibrium between CO_2 and H_2O under the conditions of his study, while Johnston and his students (5) found that several days were required for equilibrium between calcite, H_2O, and CO_2. Fig. 3 shows the change in conductivity of the $Ca(OH)_2$ solution as CO_2 was bubbled through. During the first minute the solution became turbid with the formation of $CaCO_3$ and the conductivity dropped. During the next few minutes the turbidity disappeared, the Ca being further carbonated to $Ca(HCO_3)_2$, and the conductivity increased sharply. After about 4 hours the excess $CaCO_3$ started precipitating on the walls of the vessel and the conductivity dropped slightly until after 10 to 12 hours it became constant. Since the work of Bradfield and Allison (4) showed that equilibrium between the clay, $CaCO_3$, H_2O, and CO_2 of the air was reached within 4 or 5 hours after carbonating, it is

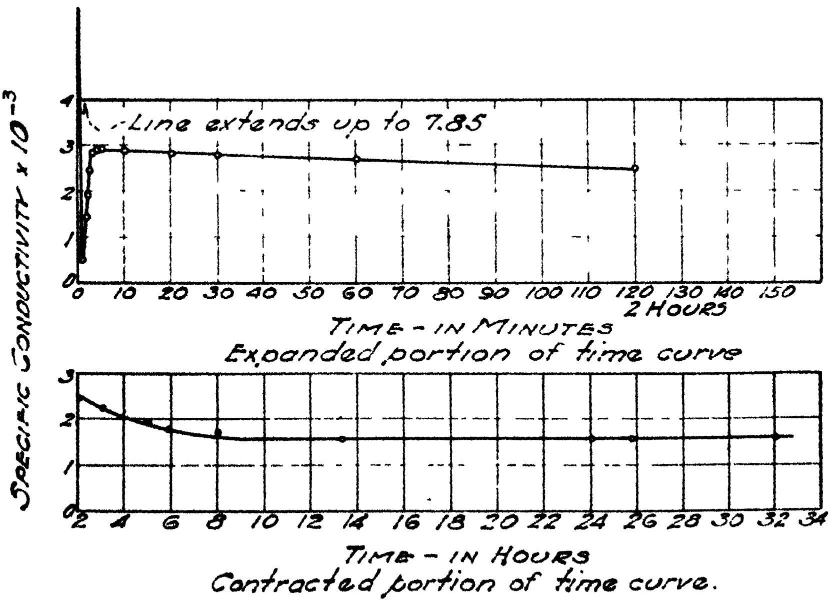

FIG. 3.—Time of equilibrium between CO_2 and $Ca(OH)_2$. Conductimetric study.

believed that in these proposed studies equilibrium would be reached between 4 and 12 hours, depending on the CO_2 pressure used.

To be sure that equilibrium was established in the clay-$CaCO_3$-H_2O-CO_2 systems, pH determinations were made after the gas mixture had been bubbled through for 15 hours. Three determinations were made on each flask over a period of 3 hours. No change in pH was observed; equilibrium had apparently been established.

A third criterion of equilibrium was obtained by studying the rate of absorption of CO_2 by CaO, H_2O, and H-clay, using a gasometric technic. The materials were introduced into a flask which was then evacuated and attached to a gas system containing a gas buret and a manometer Adjustment of gas pressure in the system was made then it was allowed to react with the mixture in the flask. After equilibrium was established at one CO_2 pressure, a higher pressure was introduced. The rates of reaction of the CO_2 with the mixture as a function of time are presented graphically in Fig. 4 and indicate

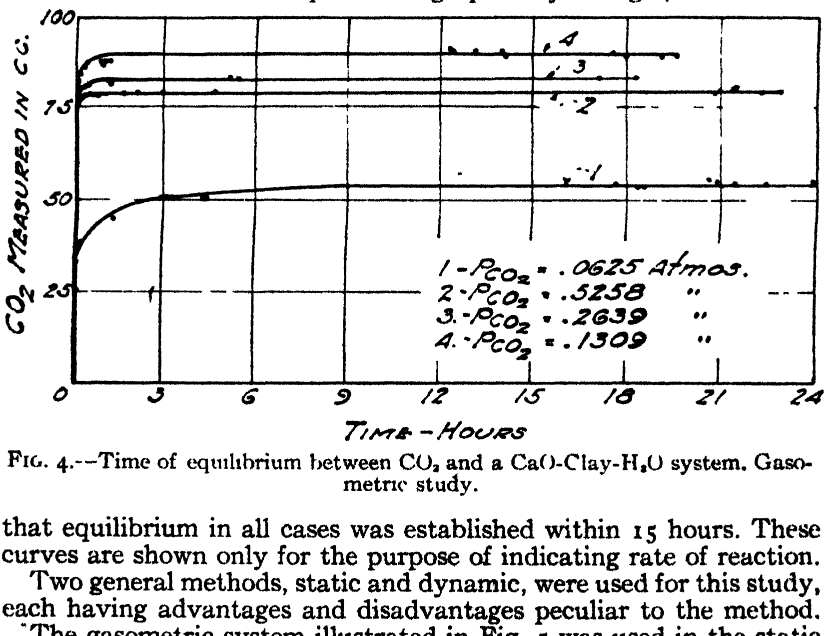

FIG. 4.—Time of equilibrium between CO_2 and a CaO-Clay-H_2O system. Gasometric study.

that equilibrium in all cases was established within 15 hours. These curves are shown only for the purpose of indicating rate of reaction.

Two general methods, static and dynamic, were used for this study, each having advantages and disadvantages peculiar to the method.

The gasometric system illustrated in Fig. 5 was used in the static method of study. The materials on which a study was made were put into the flask D, the total volume of which was about 75 cc. Since the flask was shaken vigorously (by a device not shown) during the reaction, it was necessary to have a suspension dilute enough to be agitated easily, but of small enough volume to stay in the bulb part when shaken. About 2 grams of clay and 30 cc of water were used. This proportion seems to have been about right.

The technic in this study consisted in introducing the dry clay and some rough glass beads into the flask, then adding CO_2-free H_2O and the freshly calcined CaO from a weighing vial, evacuating to remove air, closing the flask, and finally attaching it to the system.

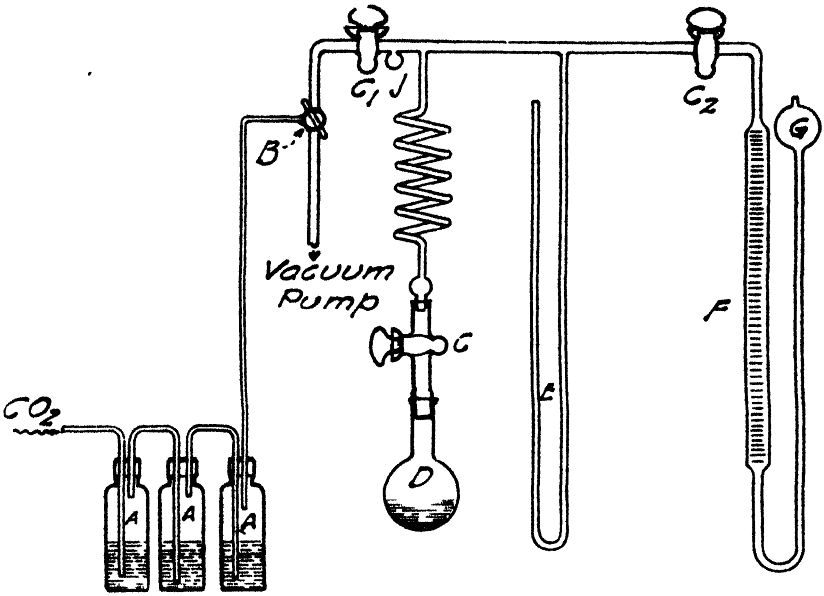

FIG. 5 Apparatus for static study.

By means of the stop cocks shown, any part of the system could be evacuated by the pump. The enlargement J contained a very small quantity of water for keeping the system filled with H_2O vapor. With the flask still closed to the rest of the system, CO_2 was introduced through the flasks marked A containing a $CaCO_3$-H_2O mixture This CO_2 was brought to equilibrium at a pressure indicated by the manometer E. The flask was then opened to the system and the CO_2 allowed to react with the materials studied. The quantity of CO_2 absorbed was measured by the gas buret F. After equilibrium was established at one pressure, the flask was closed and the procedure repeated for a higher pressure.

With such a method of study, very little analytical work is required and the rate of reaction can be easily observed. As indicated above when equilibrium is established at one pressure, another pressure can be studied by doing nothing more than changing the pressure and making the required observations and calculations.

Temperature control within narrow limits is necessary over a relatively large system when this method is used, partially because of the temperature effect on reaction, but chiefly because of sharp changes in the vapor pressure of H_2O at the temperatures used. This method was discontinued after several fairly satisfactory runs were made, because facilities for temperature control were not available. For measuring pressures of CO_2 comparable to those commonly found in soils, another type of manometer would be necessary. Since this system is subjected to rigorous strains for several days at reduced pressures, leaks can be very serious. Another possibility of error could be partial carbonation of the CaO in mixing the materials.

Despite these difficulties it is believed that this method would prove very satisfactory for studying this problem.

The dynamic method differed from that proposed by Bradfield and Allison only in the composition of the gas used. With this method very low CO_2 pressures can be used, pH studies can be made with ease, and a number of replications can be set up. $CaCO_3$ or $Ca(OH)_2$ may be used as the source of Ca, but since the time of reaction is so great where $CaCO_3$ is used, either $Ca(OH)_2$ or CaO would be preferable. The greatest disadvantages of this method are the difficulties in maintaining gas mixtures of constant composition, the time-consuming analytical work, and the fact that a sample of clay can be used only at one CO_2 pressure.

Fig. 6 illustrates one type of apparatus used in this study. The flowmeters C and D, the mercury escape valves A and B, and the mixing chamber E were used for giving a constant mixture of CO_2

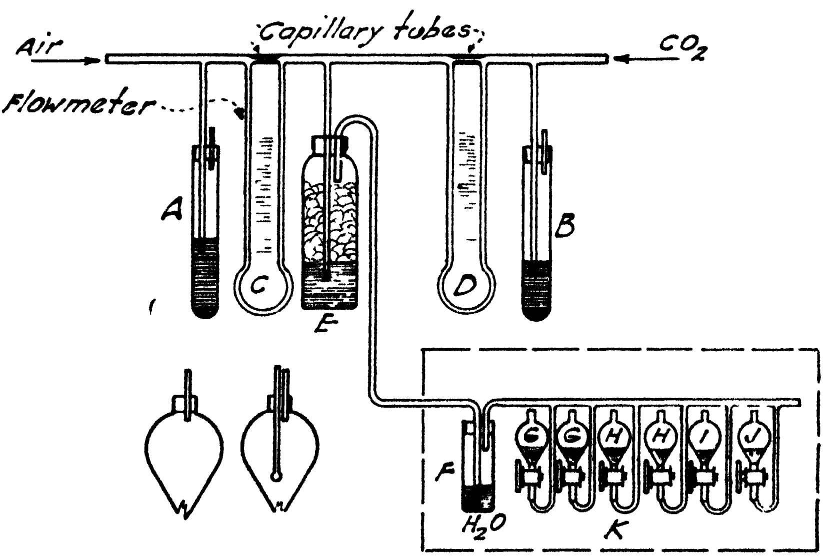

FIG. 6.- Apparatus for dynamic study.

and air which pass through F, containing water at the temperature of the water bath K. Flasks G, H, I, and J are ordinary 120-cc separatory funnels with the delivery tubes turned up for connecting to the gas line. Flasks G contained the clay-$Ca(OH)_2$ mixture, while flasks H contained an equal amount of $Ca(OH)_2$ but no clay and served as blanks. Flask I contained a small amount of $Ca(OH)_2$ for pH studies, while flask J contained NaOH for pH determinations from which the CO_2 content of the gas mixtures were calculated according to the method of Wilson and associates (12).

The clay-$Ca(OH)_2$ system was treated as follows: Approximately 2 grams of the dry clay and 75 cc of $Ca(OH)_2$ of known normality were introduced with several glass beads into the reaction flasks, which were then closed by means of rubber stoppers and weighed.

Air was bubbled through for 2 hours in order to mix the materials completely. The glass beads broke up the clay particles during this treatment, after which the system was carbonated with pure CO_2 for 5 minutes followed by an overnight bubbling with the desired CO_2-air mixture. After about 12 hours pH determinations were made on the system by means of a glass electrode and a Leeds and Northrup type K potentiometer using a Lindeman quadrant electrometer as a null-point instrument. Accuracy greater than 1 mv. was not attempted. The temperature of the reaction bath was 30° C±.1°. Three pH determinations were made over a period of 3 hours and when no change was observed equilibrium was considered to have been reached. A small amount of $Ca(OH)_2$ in flask I received the treatment above After equilibrium had been established in the systems, the flasks G and H were closed, reweighed, and analyzed for total CO_2 according to the method of Schollenberger (9). Just before the analysis was made, enough CO_2-free water to fill the flask was introduced from the bottom. This eliminated the necessity of including the CO_2 above the equilibrated suspension in the analysis. The water was very carefully introduced, requiring about 1 minute, and seems to have done nothing more than effect a displacement of the gas, though it is possible that some small quantity of CO_2 in solution was lost.

The data obtained by these studies are summarized in Table 1 and Fig 7. The amount of Ca absorbed by the clay was obtained by subtracting the amount of CO_2 observed from the total calculated amount based on CO_2 absorption in water and the solubility of

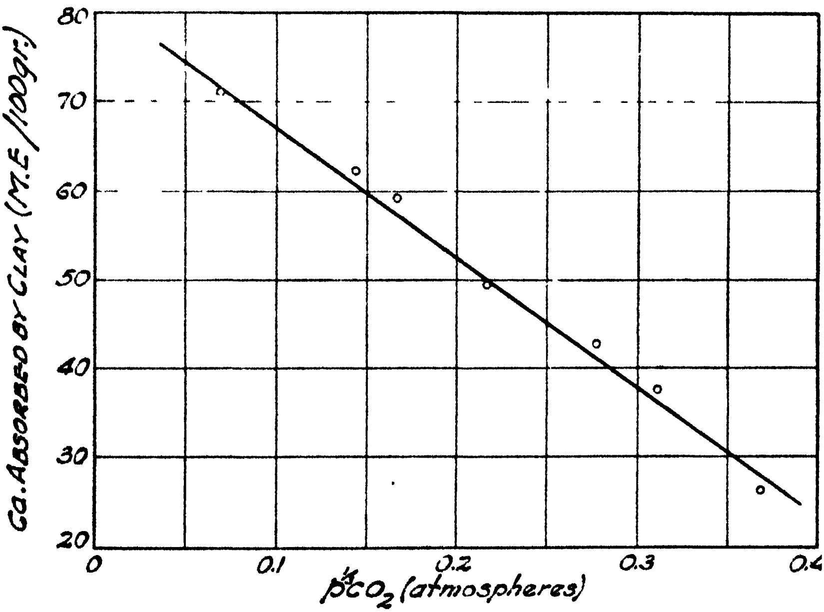

FIG. 7 —Effect of CO_2 pressure on calcium absorbed by colloidal clay as determined by dynamic study.

$Ca(HCO_3)_2$, with the assumptions already mentioned that the $Ca(HCO_3)_2$ solubility would not be affected by the clay. Since, however, the pH of the clay system was invariably higher than the pure carbonate system, a second calculation might be made of the bicarbonate solubility from pH values of the clay system using the mass action equations, or modifications of them, as follows:

$$\frac{[H^+][HCO_3^-]}{[H_2CO_3]} = K_1 \qquad 1$$

$$H_2CO_3 = \frac{aP_{CO_2}}{22.267} \qquad 2$$

$$\text{and } [HCO_3^-] = \frac{K_1 \times a \times P_{CO_2}}{[H^+] \times 22.267} \qquad 3$$

Such a treatment of the data is not justified until further study is made of this system.

In Table 1 are shown the values obtained by this study. From these data it is seen that the pH values observed in the clay systems were consistently higher than that of the pure $CaCO_3$ system at the same CO_2 pressure. It is probable that the actual differences between the pH values of the two systems are partially obscured by the experimental error in determining the values and that the actual differences would be some definite function of the CO_2 pressure. There is shown a very close agreement between the observed and calculated pH values of the pure $CaCO_3$ systems, differences in all cases being reasonably within the limits of experimental error of the glass electrode apparatus. A study of these pH values, possible through this method of study, would furnish much needed information about clay-$CaCO_3$-CO_2-H_2O systems that would explain many controversial questions.

TABLE 1.—*The effect of CO_2 pressure on pH and bicarbonate solubility in Clay-$CaCO_3$-H_2O and $CaCO_3$-H_2O systems.*

CO_2 pressure (atmospheres)	(P_{CO_2}) (atmospheres)	pH clay system	pH clay system minus pH $CaCO_3$ system	Observed pH $CaCO_3$ system	Calculated pH $CaCO_3$ system*	Calculated pH minus observed pH $CaCO_3$ system	HCO_3 molality mml/kilo H_2O†	M.E. Ca absorbed per 100 grams clay
1	2	3	4	5	6	7	8	9
0.00033	0.069	8.57	0.15	8.42	8.37	−0.05	0.97	71.3
0.00295	0.144	7.97	0.31	7.66	7.76	0.10	2.15	62.4
0.00467	0.167	7.87	0.33	7.54	7.61	0.07	2.42	59.2
0.00999	0.215	7.67	0.35	7.32	7.38	0.06	3.10	49.7
0.02130	0.277	7.57	0.36	7.21	7.16	−0.05	4.05	43.0
0.03010	0.311	7.28	0.21	7.07	7.06	−0.01	4.52	37.9
0.05000	0.368	7.19	0.28	6.91	6.92	0.01	5.42	26.4

*$pH = pK_1 - .5\sqrt{\mu} + \log [HCO_3^-] - \log [H_2CO_3]$.

†From Fig. 1.

The quantity of calcium absorbed by the clay is plotted as a function of the cube root of the CO_2 pressure in Fig. 7, and is shown to be indirectly proportional to the pressure so expressed. The decrease in calcium absorption as the CO_2 pressure is increased could be predicted from a study of Fig. 2 which shows that the relative H-ion concentration increases much more rapidly than does the Ca-ion concentration as the CO_2 pressure is increased within the ranges studied.

The data presented are an average of three determinations at most of the designated pressures. Many early studies were so inconsistent as to seem almost valueless at the time. Later studies indicated that equilibrium was probably never reached in some of these earlier studies. Constant pressure of gas was difficult to maintain. Prepared gas mixtures at definite CO_2 pressures would eliminate this possibility of error. The chief cause of inconsistencies was found to be due to the almost irreversible drying of the colloidal clay. In some of the studies it was found that equilibrium was not reached even though the gas mixture was bubbled through for 48 to 60 hours, while in other cases and at the same pressure, equilibrium was apparently reached within 10 to 12 hours. It was found that the glass beads were not doing a complete job of breaking down the clay particles in those flasks which apparently did not reach equilibrium. Just as soon as the beads were violently agitated, which completely broke down the aggregates, equilibrium could be quickly established. This breaking down of the aggregates was often accomplished by passing through air or carbon dioxide at a rapid rate before the gas mixture was used. Difficulties with the almost irreversible drying of colloidal clay were also experienced by Baver and Scarseth (1) who reported an exchange capacity of 30 M.E. for dried Lufkin colloidal clay after it had been dried as compared with 82 M.E. (2) for the completely hydrated colloid.

SUMMARY AND CONCLUSIONS

In this study some of the problems in the reaction of calcium carbonate and clay have been considered. Reference has been made to earlier work in which conditions of equilibrium in respect to carbon dioxide pressure, so vital in studies of this nature, have been overlooked. The absorption of Ca by a hydrogen colloidal clay from an excess quantity of $CaCO_3$ at different CO_2 pressures has been proposed for clearing up some of the problems in the study of the clay-$CaCO_3$ system. Methods for these studies have been described.

Equilibrium in the clay-$CaCO_3$-H_2O-CO_2 system can be established within 12 to 15 hours when $Ca(OH)_2$ or CaO is used as a source of Ca.

The pH values observed in $CaCO_3$-H_2O-CO_2 systems agree very well with the calculated values obtained by the use of accepted solubility values. The pH values of clay-$CaCO_3$-H_2O-CO_2 systems are higher than pH values of corresponding $CaCO_3$-H_2O-CO_2 systems making improbable the earlier assumption that soil has no effect on the HCO_3^- concentration.

The CO_2 pressure does affect the absorption of calcium by a hydrogen clay. Increase in CO_2 pressure in $CaCO_3$-H_2O-CO_2 systems increases the relative concentration of H ions much more than it does

the Ca-ion concentration. This increase in H-ion concentration, coupled with its much greater specific absorbability, accounts for the decrease in Ca absorption as the CO_2 pressure is increased.

It is shown that over the lower CO_2 pressures, this change in Ca absorption is a linear function of the cube root of the CO_2 pressure expressed in atmospheres.

The small quantity of data presented does not warrant more specific conclusions, especially in view of many inconsistencies. Further study should be made to establish definitely or disprove the relationships suggested.

LITERATURE CITED

1. BAVER, L. D., and SCARSETH, G. D. The nature of soil acidity as affected by the SiO_2—sesquioxide ratio. Soil Sci., 31:159-173. 1931
2. ———— and WINTERKORN, HANS. Sorption of liquids by soil colloids: II. Surface behavior in the hydration of clays. Soil Sci., 40:403 419. 1935.
3. BOHR, CHRISTIAN. Definition und Methode zur Bestimmung der Invasions und Evasionscoefficienten bei der Auflösung von Gasen in Flussigkeiten. Werthe der genannten Constanten sowie der Absorptionscoefficienten der Kohlensaure bei Auflösung in Wasser und in Chlornatriumlosungen. Ann. der Physik und Chem., 68:500-525. 1899.
4. BRADFIELD, R., and ALLISON, W. H. Criteria of base saturation in soils. Trans. Second Comm. and Alkali-Subcommittee Intern. Soc. Soil Science, A:63-79. 1933.
5. FREAR, G. L., and JOHNSTON, JOHN. The solubility of calcium carbonate (calcite) in certain aqueous solutions at 25°. Jour. Amer. Chem. Soc., 51: 2082-2093. 1929.
6. JENNY, HANS. Studies on the mechanism of ionic exchange in colloidal alum inum silicates. Jour. Phys. Chem., 36:2217-2258. 1932.
7. JENSEN, S. T. Ueber die Bestimmung der Pufferwirkung des Bodens. Intern. Mitt. Bodenkundo, 14:112. 1924.
8. JOHNSTON, JOHN. The solubility product constant of calcium and magnesium carbonates. Jour. Amer. Chem. Soc., 37:2001-2020. 1915.
9. SCHOLLENBERGER, C. J. Determination of carbonates in soil. Soil Sci., 30:307 324. 1930.
10. TRUOG, E., TAYLOR, J. R. JR., PEARSON, R. W., WEEKS, M. E., and SIMONSON, R. W. Procedure for special type of mechanical and mineralogical soil analysis. Soil Sci. Soc. Amer. Proc., 1:101-111. 1936.
11. WIEGNER, G. Ionenumtausch Und Structur. Trans. Third Intern. Congress of Soil Science, III, Commission II:5-28. 1935.
12. WILSON, P. W., ORCUTT, F. S., and PETERSON, W. G. Determination of carbon dioxide in gas mixtures. Ind. and Eng. Chem., Anal. Ed., 4:357 361. 1932.

A STUDY OF HIGH AND LOW LEVELS OF SOIL FERTILITY RESPONSE TO TWO VARIETIES OF SUGAR BEETS[1]

L. A. Hurst, A. W. Skuderna, and C. W. Doxtator[2]

THE reactivity of certain commercial varieties of sugar beets to varying levels of soil fertility has long been observed by trained investigators, sugar company fieldmen, and farmers engaged in growing this crop. European beet seed firms engaged in the business of supplying the United States trade with beet seed, sought to meet the need by furnishing a choice of varieties listed as tonnage, intermediate and sugar types, designed to meet the varying needs of soil and climatic conditions of the areas where sugar beets are grown.[3] More recently with the development of domestic varieties of sugar beets, either resistant to certain diseases or better adapted to certain areas—to the extent that more than 85% of domestic needs for beet seed is now supplied through home sources—the number of varieties has been reduced, making it necessary to develop a more adequate program of soil fertilization fitted to the variety or varieties found best for any one area.

To this end the present study, which is a forerunner of other studies that are to follow, was undertaken. The results presented herein are therefore to be considered in the nature of a progress report.

EXPERIMENTAL PROCEDURE

The soil type on which this study was conducted was classified as Rocky Ford fine sandy loam with a pH of 7.5. The field was broken out of alfalfa in 1935 and planted to barley in 1936 and to onions in 1937. In the fall of 1937 an 8-ton coating of cattle manure was applied per acre immediately prior to fall plowing.

In the spring of 1938 the field was prepared for planting. Two domestic varieties of sugar beets were used, one being a "sugar" variety and the other a "tonnage" variety. Both of these varieties were somewhat more uniform as to type than the European varieties used in previous tests.

The commercial fertilizers used were 4-16-4, 4-16-0, 0-16-4, and 0-16-0, in comparison with the unfertilized check plats. The same amount of plant food per acre was applied from each mixture assuring thereby a comparison of equal amounts of plant food regardless of the difference in formula used. The rates of application for each fertilizer formula were 200, 400, and 600 pounds per acre of the equivalent of a 20% mixture, or 40, 80, and 120 pounds per acre, respectively, of total plant food. All the fertilizer was applied with the seed at time of planting.

The plat arrangement was fully randomized and of such layout as to permit unbiased evaluation of interactions between varieties, treatments, and rates of fertilizer application. Each treatment was replicated seven fold, the plats being

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[1]This study was conducted in cooperation with the Division of Soil Fertility Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Crystal Sugar Co., Rocky Ford, Colorado.

[2]Biochemist, Division of Soil Fertility Investigations and General Manager and Plant Breeder, respectively, American Beet Seed Company.

[3]Skuderna, A. W., *et al.* Evaluation of sugar beet types in certain sugar beet growing districts in the U. S. U. S. D. A. Circ. 476. 1938.

TABLE 3.—*Variance of yield, sucrose percentage, and sugar production per acre for kind and rate of application applied to two varieties of sugar beets.*

Variation due to	Tons beets per acre		Percentage sucrose		Pounds sugar per acre	
	Mean squares	F	Mean squares	F	Mean squares	F
Varieties	229.795	43.25†	4.785	13.25†	16,757,320	35.51†
Kinds of fertilizer	14.992	2.82	1.283	3.55†	1,823,385	3.86†
Rates of application	0.444	0.08	0.54	0.98	145,466	0.31
Varieties × kinds of fertilizer	2.752	0.52	0.309	0.86	304,595	0.65
Varieties × rates of application	12.588	2.37	1.155	3.20*	1,842,490	3.90*
Kinds fertilizer × rate of application	1.164	0.22	0.271	0.75	114,872	0.24
Varieties × kinds fertilizer × rate of application	9.999	1.88	1.302	3.61†	1,315,149	2.79†
Error	5.315	——	0.361	——	471,969	——
Required for significant individual treatment	2.46 tons	——	0.63%	——	734 lbs.	——
Required for average of 4 treatments	1.23 tons	——	0.32%	——	367 lbs.	——

*Significance beyond 5% point
†Significance beyond 1% point.

SUMMARY

Two domestic varieties of sugar beets designated as a "sugar" and a "tonnage" variety were compared in their reaction to different fertilizers and to different rates of fertilizer application. It was found that with the 'sugar' variety 400 and 600 pounds per acre of fertilizer lowered performance insignificantly as compared with 200 pounds of fertilizer. With the 'tonnage' variety 400 and 600 pounds of fertilizer slightly increased yields, sugar percentage, and sugar per acre, although only the 600-pound application produced significant differences. Attention is called to the need of determining whether a variety is a "strong" or "weak" feeder so that a more adequate program of soil fertilization may be developed.

AVAILABILITY OF SOIL MOISTURE, PARTICULARLY AS AFFECTED BY DEPTH, IN THE SOIL OF THE KENTUCKY EXPERIMENT STATION FARM AT LEXINGTON[1]

P. E. KARRAKER AND C. E. BORTNER[2]

IN Bulletin 272 of the Kentucky Agricultural Experiment Station, data are given showing that in many years lack of moisture prevents corn yields on the Experiment Station farm from reaching the level made possible by the fertility of the soil and that the reason for this is the poor distribution of rainfall during the growing season. Obviously this moisture limit to crop yields also is affected by the extent to which crops can utilize water held in the soil at different depths.

The general belief probably is that most crops obtain water from the first 5 to 6 feet of soil mainly by penetration of roots into the deeper layers, capillary movement no longer being thought of much importance in this connection. The basis for believing that crops root effectively at 4 to 5 feet, as pointed out by other writers[3] is the result of extensive studies of root development made by Weaver and co-workers in soils of the subhumid section of the United States where, because of the open nature of the subsoil, it is to be expected that crops would root deeper than in most soils in the eastern part of the country.

By considering the amount of water the soil on the Experiment Station farm will hold in relation to the crop requirement, it is apparent either that the crop can use water only from a comparatively shallow surface layer or that most of the water in the soil is held so firmly that crops cannot get it. Assuming the capacity of the soil of the surface foot to hold and deliver water to the crop to be 20% of its dry weight (maximum field capacity, about 30%), the surface foot layer (weight per acre, 4,000,000 pounds) would furnish water equal to approximately 2.6 surface inches. Seemingly it should be able to deliver 2 inches of this amount sufficiently rapidly so that the crop would suffer very little for water during the time this is being used. Since during the period of greatest use by the corn crop probably not over 1 inch of water is being removed from the soil per week, the surface foot alone should furnish the crop with enough water for almost 2 weeks, which is approximately the length of time the corn crop at this state of growth will go without injury in fair weather.

The soil used for the agronomy work is Maury silt loam. The surface soil works as a mellow silt loam and the subsoil is friable and well drained. Limestone rock is reached at from 6 to 10 feet, openings into

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[3]FARRIS, NOLAN F. Root habits of certain crops as observed in the humid soils of New Jersey. Soil Sci., 38:87–111. 1934.

SPRAGUE, HOWARD B. Root development of perennial grasses and its relation to soil conditions. Soil Sci., 36:189–209. 1933.

which facilitate good drainage; however, the entire profile is high in clay. Mechanical analyses were made of samples from a profile in the county in connection with the soil survey of Fayette County, Kentucky (Bureau of Chemistry and Soils, Series 1931, No. 25). The plow

TABLE 1.—*Rainfall at Lexington, Ky., January 1 to August 31, inches.*

Month	Weather Bureau, 1930	1936		50-year average to 1932
		Weather Bureau	Gauge on farm	
January	4.44	4.00	2.88	4.10
February	2.91	2.07	1.68	3.06
March	2.54	4.43	4.46	4.34
April 1	0.28	0.37	0.10	
2	0.06	0.05	0.29	
3	0.05	0.03	—	
4	—	0.02	—	
5	0.10	2.15	—	
6	0.11	0.22	2.39	
9	—	1.34	0.55	
10	—	0.15	0.82	
11	—	0.33	0.15	
12	—	0.01	0.39	
15	—	0.05	—	
16	0.01	—	0.06	
17	0.06	—	—	
20	0.01	—	—	
21	0.01	0.43	—	
22	—	—	0.47	
28	0.02	0.34	—	
29	0.15	0.27	0.55	
30	—	—	0.35	
April, total	0.81	5.76	6.12	3.37
May 1	—	0.07	—	
2	—	—	0.15	
10	0.02	0.03	—	
11	0.85	0.06	—	
13	0.51	0.92	0.98	
14	—	—	0.16	
17	0.95	0.01	—	
18	0.43	0.36	—	
19	0.45	0.01	0.47	
23	0.08	—	—	
29	0.06	—	—	
May, total	3.35	1.46	1.76	3.49
June 6	0.88	—	—	
7	—	1.06	0.58	
8	—	0.01	0.50	
11	—	0.04	—	
16	0.18	—	—	
17	0.26	—	—	
20	0.07	—	—	
24	0.50	—	—	
30	—	0.07	—	
June, total	1.89	1.18	1.08	3.95

TABLE 1.—*Concluded.*

Month	Weather Bureau, 1930	1936		50-year average to 1932
		Weather Bureau	Gauge on farm	
July 1	0.05	0.08	—	
2	—	0.01	0.13	
9	0.21	—	—	
10	—	0.02	—	
11	—	0.50	—	
12	0.03	—	0.54	
13	0.11	—	—	
14	—	0.04	—	
15	—	0.32	—	
16	—	0.56	1.01	
18	—	0.02	—	
24	—	0.33	0.48	
25	—	0.79	—	
26	0.05	0.07	0.98	
28	—	0.01	—	
July, total	0.45	2.85	3.14	3.94
August 4	—	0.01	—	
5	0.06	0.03	0.11	
6	0.06	0.42	0.25	
7	0.19	—	0.29	
8	0.12	—	—	
9	0.07	—	—	
10	0.07	0.01	—	
13	0.02	0.02	—	
14	0.81	—	—	
21	0.06	0.16	—	
22	0.06	0.03	—	
23	0.17	—	—	
27	—	0.52	—	
28	—	—	0.55	
29	—	0.06	—	
30	—	—	0.06	
August, total	1.69	1.26	1.26	3.40
Total for 8 months	18.08	23.01	22.38	29.65

layer contained 37.9% clay (<.005 mm) and the 34- to 66-inch layer 62.2% clay. As a measure of humus content, the acre plow layer on the farm contains 3,000 to 3,500 pounds of nitrogen.

The 1930 growing season was very dry in Kentucky and summer crops were almost an entire failure. The 1936 growing season was also quite dry and summer crops were greatly injured. Precipitation at Lexington from January 1 to August 31 in these years and on the average is shown in Table 1.

The 1930 data were taken from the records of the Weather Bureau station about 1 mile away and hence may have been somewhat different from the rainfall on the farm. In 1936, data also were obtained from a gauge on the farm near the areas sampled.

In both these years, the soil on the Experiment Station farm in different cropping areas was sampled by layers and moisture and

nitrate determined in each. In 1930 the samples were taken the first of August and in 1936 the last of July (23rd and 24th). The results are reported in Tables 2 and 3.

In 1930 the samples in the scraped area and under the bluegrass-white clover sod were composites of five cores; under the corn, of two cores; and under the alfalfa, of four cores. In 1936 all samples were composites of four cores and sampling was done to rock.

TABLE 2 — *Total water and nitrate nitrogen at different depths in the soil of the Kentucky Experiment Station farm from August 1, 1930, based on soil dried at 105°C*

Depth sampled	No crop since 1923, kept scraped bare		Continuous bluegrass and white clover since 1923	
	Water, %	Nitrate nitrogen ppm	Water %	Nitrate nitrogen, ppm
0-3 in	10 55	8 5	3 97	2 5
3-12 in	14 58	6	5 81	2 5
1-2 ft	18 54	5	9 62	Trace
2-3 ft	22 25	4	16 49	0
3-4 ft	23 67	6	25 68	0
4-5 ft	26 60	8	31 49	1
5-6 ft	31 26	12	33 09	0

Depth sampled	Corn sample taken 6 ins from hills, rotation corn, wheat, sod crop		Corn sample taken where diagonals between adjoining hills cross		Alfalfa second year	
	Water, %	Nitrate nitrogen, ppm	Water, %	Nitrate nitrogen, ppm	Water %	Nitrate nitrogen ppm
0-7 in	6 86	32	7 65	44 5	7 36	13 5
7-12 in	9 53	3	9.97	4	6 96	4
12-18 in	11 00	3	11 43	1 5		
18-24 in	15 06	1 5	18 83	1 5	11 13	Trace
2-3 ft	20 24	1 5	21 02	2	20 22	Trace
3-4 ft	25 81	1 5	25 01	2 5	24 35	Trace
4-5 ft	30 57	2	28 99	1	28 60	Trace
5-6 ft	33 66	2 5	34 03	3 5	31 73	Trace

Other determinations of total water in the soil on the Experiment Station farm, made in connection with various studies, show that the maximum field capacity of the soil of the plow layer is about 30%, of the remainder of the surface foot 2 or 3% less, probably because of a lower humus content, and below the surface foot 28 to 30% again, increased clay content here offsetting decreased humus. The hygroscopic coefficient determined over water in one sample each of the plow layer and the 24- to 30-inch layer is 7.12% and 14 24%, respectively.

In general the data (Tables 2 and 3) are similar for the two years. In both years, below 4 to 5 feet the soil contains approximately its maximum field capacity and above this, in most areas, there is a gradual decrease to 20 to 22% in the 2- to 3-foot depth, the decrease

being nearly the same in the uncropped and cropped areas. There is a further decrease in the top 2 feet. Excepting the samples taken from midway between corn hills in 1936, this is considerably greater in the cropped areas than in the uncropped areas. This indicates that in

TABLE 3.—*Total water and nitrate nitrogen at different depths in the soil of the Kentucky Experiment Station farm the last of July 1936, based on soil dried at 105° C.*

Depth sampled	Fallow in various sod crops for several years previous: Water %	Fallow in various sod crops for several years previous: Nitrate nitrogen ppm	Bluegrass white clover since 1927: Water %	Bluegrass white clover since 1927: Nitrate nitrogen ppm
0-7 ins.	12.35	2.05	12.35	8
7-12 ins.	15.20	6	10.86	3
1-2 ft.	17.92	2	13.63	Trace
2-3 ft.	20.48	2.5	19.47	None
3-4 ft.	21.95	3	22.85	None
4-5 ft.	22.24	3	24.85	None
5-6 ft.	21.80*	2.5	28.86	None
6-7 ft.	27.22	3.5	30.20	None
7-8 ft.	28.53	2.5	30.89	None
8-9 ft.	29.03	1.5	28.70	None
9-10 ft.	—	—	27.87	None

Depth sampled	Corn sample taken 8 ins. from hills, rotation corn, wheat, sod crop: Water %	Corn sample taken 8 ins. from hills, rotation corn, wheat, sod crop: Nitrate nitrogen ppm	Corn sample taken where diagonals between adjoining hills cross: Water %	Corn sample taken where diagonals between adjoining hills cross: Nitrate nitrogen ppm	Alfalfa, third year: Water %	Alfalfa, third year: Nitrate nitrogen ppm
0-7 ins.	9.64	32	18.76	20.5	10.13	15
7-12 ins.	11.60	7.5	15.07	6	11.35	4
1-2 ft.	15.30	1	18.06	2	13.76	1.5
2-3 ft.	21.50	2.5	22.69	Trace	18.06	Trace
3-4 ft.	23.76	None	23.60	None	24.53	None
4-5 ft.	25.00	None	25.47	None	28.53	None
5-6 ft.	27.87	None	28.04	None	26.58	None
6-7 ft.	28.88	None	28.86	None	20.91	None
7-8 ft.	28.70	None	30.89	None	18.34	Trace
8-9 ft.	28.88	None	30.89	None	20.91†	Trace
9-10 ft.	31.06	Trace	32.98	None	—	—
10 ft.	(rock at 9½ ft.)		31.75 (rock at 10½ ft.)	None		

*This figure appears to be out of line for some unknown reason.
†Considerable concretionary material was present in the bottom layers of the soil in this area which probably accounts for the lower percentages here.

both years the crops took most of their water from the top 2 feet of soil. However, the sod crop took some water from the 2- to 3-foot depth in 1930 and a small amount from this depth in 1936, and the alfalfa took some from this depth in both years. It should be considered that the crops no doubt reduced evaporation somewhat on

the cropped areas below that on the uncropped areas so that, even though there was no greater reduction in soil moisture below 2 feet in the cropped than in the uncropped areas, some water may have been obtained by the crop from this depth.

In connection with these field studies a quantity of soil was taken from the plow layer and also from the 24- to 30-inch layer and corn plants grown in these lots in ½-gallon, glazed earthernware jars to find out how much of the water in the soil was unavailable to the plants. The soils used for determination of hygroscopic coefficient reported above were from these lots. The subsoil was used in two conditions, *viz.*, pulverized and in blocks. There were four jars for the surface soil and for each of the subsoil conditions. Fifteen hundred grams of air-dry soil were used in each jar of the surface soil and pulverized subsoil. One block of the subsoil was used in each of these jars, the blocks varying in weight from 1,303 to 1,843 grams. After the soil was placed in the jars, water equal to 25% of the weight of soil and 1 gram of KNO_3 per jar were added. Because of the high phosphorus content of the soil no phosphate was added. To check on evenness of distribution of nitrate through the blocks, and because any unevenness might affect root distribution, blocks were placed in two additional jars and nitrate added as above After 7 days nitrate was determined in the outside ½-inch layer and in the inside of the block from these jars. As an average of the two jars the nitrate in the outside layer, stated as pounds of nitrate-nitrogen per 2 million pounds of dry soil was 185, and in the inside part, 191.

Five grains of first generation hybrid corn were planted in each jar but in four of the jars only four plants grew. Fine gravel was filled in around the blocks of soil in the jars where the subsoil was not pulverized and placed as a mulch on all the jars. Later, sand was placed on top of this. During the first part of the experiment the jars were in the greenhouse; later, to prevent temporary wilting during bright days and to obtain more even temperatures, the jars were moved to the northern exposure of a well-lighted room. The corn was planted March 6, 1937, and the experiment terminated April 29. At this time all plants were dead in the jars containing the subsoil and all either had just died or were almost dead in the jars containing the surface soil. Most of the plants were living in all jars on April 12. The roots were mainly on the outside of the blocks of subsoil but were well distributed through the soil in the other jars although they were somewhat more numerous in the top than in the bottom half in most jars.

Capillary and hygroscopic water were determined in the soil of the jars, the top and bottom halves being sampled separately. There was very little difference between the two halves. Averaging the four jars in each experimental condition, the total percentages of water were as follows, the percentage of the hygroscopic water (soil dried at 105° C) also is shown.

	Total %	Hygroscopic %
Surface soil	12.0	4.5
Subsoil, pulverized	23.1	7.2
Subsoil, in blocks	24.0	7.1

It will be noted that in both dry years the water in the surface foot under the crops was below the above surface soil percentage, except in 1938 midway between the hills of corn. Considering the 2- to 3-foot depth, it will be noted that in both the cropped and uncropped land, the amount in the field is below the subsoil percentage above and, as noted previously, there was no great difference between the cropped and uncropped areas in the amount of moisture present. How much of this reduced amount in the field is due to the crop and how much to evaporation cannot be said, although the effect of the crop on the layers under the surface seems to be much less than expected.

Some observations of root development were made in both years. In 1930, 6 days after the soil was sampled for the moisture determinations, a trench was dug to a depth of 38 inches with a vertical face directly under a hill of corn in the area sampled and extending midway to the hill on either side. Most of the roots were in the plow layer. Only a few extended below 30 inches and very few below 38 inches and these were very small. Below the plow layer there was a gradual but fairly rapid decrease in roots with depth. When the sampling for moisture was done, the corn plants, two in each hill, averaged 6 feet high and 1 inch in diameter near the base. They were in tassel and many were silking. They showed serious drought injury. The crop, Boone County White, was planted May 5. Showers in May and the first of June made fair growth possible the first of the season. There was no yield of grain, however, on account of lack of rain in July and August.

In 1936, at the time the soil was sampled for determination of moisture, observations were similarly made of root development in another plat of corn on the farm. While classified as Maury silt loam, the subsoil here is not as friable as in the areas sampled for moisture. The roots were mainly in the plow layer and decreased very rapidly below this to 10 inches and gradually below this. Few roots were observed below 24 inches and very few below 32 inches (the greatest depth of observation). The total moisture in samples of soil from locations 15 inches from hills (average of two locations) was determined. The percentages found were 0 to 12 inches, 13.25; 12 to 24 inches, 15.87; 24 to 36 inches, 18.90; and 36 to 42 inches, 21.21. The corn, Midland Yellow Dent, in the area sampled for determination of moisture (1936) was planted May 6. It yielded 22.9 bushels grain per acre. At the time of sampling the stalks averaged 55 inches high and ¾ to 1 inch in diameter at the base. There were two to three stalks per hill. In years of normal rainfall corn plants grow larger than the plants in these two dry years and hence probably have larger root systems; however, in both dry years the plants made fair growth up to tasseling time.

In 1936 root development also was observed under an old bluegrass-white clover soil. Most of the roots were in the surface 4 inches of soil but were numerous to a depth of 10 inches and thereafter decreased rapidly to almost none below 24 inches. The percentage of total water found in a sample removed from the 24- to 26-inch depth was 21.50.

In some casual observations not made in connection with these studies, it was observed that alfalfa roots penetrated 6 to 7 feet to rock in one area on the farm.

The data indicate rather clearly that the crops obtained no great amount of water below the 2-foot soil depth. This can be attributed in whole or in part to the failure of the crops to root effectively below this depth. To a considerable extent it also could be attributed to the strong pull of the soil of the under layers for water because of the high clay content, as a consequence of which the amount of water in these layers between that apparently unavailable to the crop and the maximum field capacity of the soil is relatively small. Perhaps the failure of the crops to root more extensively in these layers is partly due to their inability to get more water from them.

It was thought that distribution of nitrate (Tables 2 and 3) might give some additional information on moisture movement. For the most part it did not, but in 1930, in the scraped area, the decrease in nitrate content to the 2- to 3-foot depth and then an increase below this perhaps suggests that the 2- to 3-foot depth was the lower limit of movement to the surface. In passing it may be noted that the unfavorable moisture condition did not reduce nitrate production as much as it did crop growth since nitrate was higher under the crops than is expected in normal years.

It is not known how injury from lack of moisture to summer crops on the Maury silt loam compares with that on other soils in the state. Observations on the outlying experiment fields, however, indicate that there are considerable differences between soils in the state in this respect and that crops suffer from lack of rain as quickly on the Maury silt loam as on any other extensive type in the state. J. F. Freeman, superintendent of the outlying fields, has observed that on the Western Kentucky Substation at Princeton, corn on soil derived mainly from shale and sandstone (probably Tilsit silt loam) is injured less by drought than on another part of the farm where the soil is derived mainly from limestone (probably Decatur silt loam). The limestone soil is better drained than the other, but the under layers are much higher in clay, being comparable with the Maury silt loam in this respect. Observations of root penetration have not been made at any of the outlying fields.

SUMMARY

Data are reported of the moisture in different layers of Maury silt loam soil on the Kentucky Experiment Station farm in variously cropped and uncropped land in the dry years of 1930 and 1936. Below 4 or 5 feet the soil contained approximately its maximum field capacity. Above this, moisture decreased towards the surface but below 2 to 3 feet no faster in the cropped than the uncropped areas. Above 2 to 3 feet the decrease was considerably greater in the cropped than in the uncropped areas. This indicates that the crops obtained water chiefly from the top 2 to 3 feet. Observations of depth of root penetration showed that the crops did not root effectively below this depth. In pot experiments, 12% of water in the surface soil and 23 to 24% in the subsoil was unavailable to corn plants so that even if crops rooted extensively in under soil layers, the amount of water obtained here would not be great.

AGRONOMIC AFFAIRS

TENTATIVE PROGRAM FOR THE ANNUAL MEETING OF THE SOCIETY AT NEW ORLEANS

AS a result of the "show of hands" at the last annual banquet of the Society, the Executive Committee has scheduled the next annual meeting at New Orleans, November 22, 23, and 24, with the Hotel Roosevelt as headquarters. Considerable progress has been made in making up the program.

Inasmuch as the Society has not met in the South for a number of years, it seemed appropriate that the general program should be concerned with southern agriculture. Accordingly two eminent authorities have been invited to address the general session. Dean M. J. Funchess of Alabama, a past president of the Society, will speak on the subject "Agronomic Problems of the South", and Mr. W. C. Lassetter of Tennessee, Editor of the *Progressive Farmer*, will speak on "The Social and Economic Problems of Southern Agriculturists".

The main speaker at the annual banquet of the Soil Science Society of America will be Professor G W. Robinson, University of North Wales. His subject will be announced later.

In arranging the sectional programs for a group with so many common and diverse interests as the agronomists, there is bound to occur some overlapping in subject matter. As far as the annual meeting is concerned the division of the Society into a Crops Section and a Soils Section is largely for convenience in program building. Some subjects listed under the Crops Section are of almost equal interest to the soils group. The reverse is also undoubtedly true. For example, "Teaching and Extension", listed under the present tentative crops program, is of equal interest to the soils group and might just as logically be listed under the Soils Section. Any member of the Society, regardless of whether he is primarily interested in soils or crops, is, of course, free to submit a research paper before either of the Sections of the Society by making the necessary arrangements with the respective chairmen.

CROPS SECTION

Dr. F. D. Keim, chairman of the Crops Section, has submitted the following tentative outline showing the various sessions which have been arranged and the names of the respective chairmen.

Subsection I: Breeding, Genetics, and Cytology.
- **Chairman, H. H. Love, Cornell University.**
- **Session A—Statistics.**
  - **Chairman, Karl S. Quisenberry, Bureau of Plant Industry and Nebraska Agricultural Experiment Station.**
- **Session B—Cotton Breeding and Genetics.**
  - **Chairman, H. B. Brown, Louisiana Agricultural College.**

Session C—Corn Genetics.
Chairman, P. C. Mangelsdorf, Texas A. and M. College.
Session D—Rice and Sugar Improvement.
Chairman, Jenkin W. Jones, Bureau of Plant Industry.

Subsection II: Physiology, Morphology (including Nutrition), and Taxonomy.
Chairman, O. W. Dynes, University of Tennessee.
Session A—Ecological Relations of Crop Plants.
Chairman, F. D. Keim, University of Nebraska.
Session B—Crop-Weather Relations.
Chairman, H. H. Laude, Kansas State College.
Session C—The Nutritive Value of Forage Plants Grown Under Various Conditions and for Different Classes of Livestock.
Chairman, O. McConkey, Ontario Agricultural College.
Session D—Cotton Fertilizers and Diseases.
Chairman, D. G. Sturkie, Alabama Polytechnic Institute.

Subsection III: All Other Phases.
Chairman, F. D. Keim, University of Nebraska.
Session A—Cotton Regional Variety Tests.
Chairman Henry W. Barre, Bureau of Plant Industry.
1. Field results
2. Laboratory tests
3. Spinning tests
4. Exhibits

Session B—The Coordinated Agronomic Program of the T. V. A.
Chairman, T. B. Hutcheson, Virginia Polytechnic Institute.
Session C—Teaching and Extension.
Chairman, J. C. Lowry, Alabama College of Agriculture.
Session D—Cotton Fibers and Ginning and Spinning Studies.
Chairman, Ide P. Trotter, Texas A. and M. College.
1. Work in Webb's laboratory
2. Stoneville's ginning laboratory
3. Discussion and demonstration of various cotton sorters.
   (a) Presley's.
   (b) Hertel and Hancock.
   (c) Johnson's.
   (d) Suter-Webb.

Session E—Miscellaneous.
Chairman, F. D. Keim, University of Nebraska.

SOILS SECTION

Dr. William A. Albrecht, chairman of the Soils Section, has submitted a similar, although somewhat more condensed, program for the Soil Science Society of America.

Section I—Soil Physics. Miscellaneous Papers.
Chairman, G. B. Bodman, University of California.

Section II—Soil Chemistry. Miscellaneous Papers.
Chairman, J. W. Tidmore, Alabama Polytechnic Institute.

Section III—No program will be held at New Orleans in consequence of the program at New Brunswick in connection with the International Congress of Microbiology.
Chairman, A. W. Hofer, New York Agricultural Experiment Station.

Section IV—Soil Fertility. Joint Session with Crops Section.
Subject: Cotton Diseases and Fertilization.
Symposium: The Effects of Boron in Agriculture.
Chairman, J. J. Skinner, Bureau of Plant Industry.

Section V—New Developments in Soil Mapping. Forest Soils Program. Miscellaneous Papers.
Chairman, S. S. Obenshain, Virginia Polytechnic Institute.

Section VI—Changes in Soils in Consequence of (1) Irrigation, (2) Drainage, (3) Erosion, and (4) Cultivation and Fertilization. Miscellaneous Papers.
Chairman, W. L. Powers, Oregon State Agricultural College.

The program of the general meeting of the Soil Science Society of America will consist of six papers, one contributed by each of the respective sections of the Society.

The respective chairmen of the Soils Section desire to extend their call for papers and bring to attention the date of September 15 as the final date for submission of titles and abstracts. Detailed information on program regulations governing papers presented before the Soil Science Society appear on page 360 of the 1938 PROCEEDINGS.

REGISTRATION FEE

A nominal registration fee will be charged for the first time at the New Orleans meeting to help defray expenses incurred in connection with the annual meeting. Entrance to the technical sessions of the American Society of Agronomy and of the Soil Science Society will be open only to registered individuals.

MEETING OF WESTERN BRANCH OF SOCIETY

THE twenty-third annual meeting of the Western Branch of the American Society of Agronomy was held at Davis and Berkeley, Calif., June 6 to 8. The entire day of June 6 at Davis was devoted to field trips. Wednesday and Thursday, June 7 and 8, at Berkeley were devoted to the presentation of the following papers:

Inheritance of resistance to mildew in barley in the cross Duplex×Atlas. E. H. Stanford, University of California.

Production of sugar beet seed. H. E. Finnell, Oregon State College.

The effect of differences in soil moisture on the yield and quality of alfalfa seed. Ian A. Briggs, University of Arizona.

The effect of frost and scald on the germination of barley. Dr. D. D. Hill, Oregon State College.

Recent developments in our weed research program. Dr. R. J. Evans, Utah State Agricultural College.

Determining by plant response the retention of nutrient ions by soils. Dr. John P. Conrad, University of California.

Sulfofication of soil organic matter and microbiological competition with plants for sulphates. Frank G. Viets and John P. Conrad, University of California.

The role of straw in erosion control. G. R. McDole, Pacific Northwest Region, Soil Conservation Service, U.S.D.A.

Some observations on the relation of cultural practices and the addition of certain carbohydrate materials to the nitrate-supplying power of peat soils. Dr. R. A. Pendleton, Assistant Soil Technologist, Bureau of Plant Industry, U.S.D.A.

Early agricultural history in California as revealed by adobe bricks. Geo. W. Hendry, University of California.

Cooperative research between research specialists and the Extension Division in California. Burle J. Jones, University of California.

Some distinctive features of the seed certification program in California. Frank G. Parsons, University of California.

The business meeting was held on board a river steamer while enroute overnight from Sacramento to San Francisco. Dr. R. J. Evans of Utah, president of the Western Branch, was taken ill on his way to the meetings and could not attend. Officers elected for the coming year are G. R. Hyslop, Oregon State College, president; and D. C. Tingey, Utah Agricultural College, secretary. The 1940 meeting will be held at Logan, Utah. —COIT A. SUNESON, *Secretary*.

NEWS ITEMS

G. N. HOFFER, Midwest Manager of the American Potash Institute, was given the honorary degree of Doctor of Science by Purdue University on June 11. Doctor Hoffer was a member of the Purdue staff for twenty years prior to entering the service of the Institute.

ACCORDING to *Science*, Dr. S. A. Waksman, microbiologist at the New Jersey Experiment Station, has been elected a foreign member of the Royal Swedish Academy of Agriculture.

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THE EFFECT OF OXIDATION-REDUCTION POTENTIAL ON PLANT GROWTH[1]

N. J. VOLK[2]

A STUDY of the literature reveals that considerable controversy exists as regards the effect of soil Eh on plant growth. Bradfield and his co-workers (1)[3] found that the productiveness of apple trees in New York State was related to the Eh of the soils, but Stephenson and his associates (4) concluded that no such relation existed in Oregon. Sturgis (5), working with rice in Louisiana, discovered a close relationship between active organic matter and reduction in water-logged soils, but could not use the resultant Eh values of soils to predict yields of rice.

The Eh of arable Alabama soils fluctuated only about 40 to 80 millivolts during an entire year (6), and it seemed highly desirable to determine whether or not such small changes would have an effect on plant growth. The purpose of this paper is to present data obtained from greenhouse studies regarding the effect of the Eh of a nutrient solution on plant growth when oxygen was not a limiting factor.

METHOD OF INVESTIGATION

In determining the effect of the Eh and only the Eh on plant growth, it is necessary to have all factors constant except Eh, and for this reason soils could not be used since factors other than Eh, such as available oxygen, could not be controlled. Quartz sand cultures, however, were found to be satisfactory. Nutrient solution was run through the sand at such a rate that the growing plants did not appreciably change its Eh value during the entire growing period. No attempt was made to deprive the plants of oxygen.

The composition of the base nutrient solution was prepared from salts as follows:

0.056 gram boric acid C. P.
4.70 grams $CaCl_2.2H_2O$ C. P.
13.78 grams $MgSO_4.7H_2O$ C. P.
4.35 grams KH_2PO_4 C. P.
6.45 grams $NaNO_3$ (commercial)
0.034 gram $MnSO_4.2H_2O$ C. P.

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[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication March 30, 1939.
[2]Soil Chemist.
[3]Reference by number is to "Literature Cited", p. 670.

This was made up to 20 liters and adjusted to pH 6.0 with H_2SO_4.

To vary the Eh of the above nutrient solution it was necessary to add something that would not alter its nutrient value. A great many organic compounds were tested for their toxicity to plants at various concentrations and for their

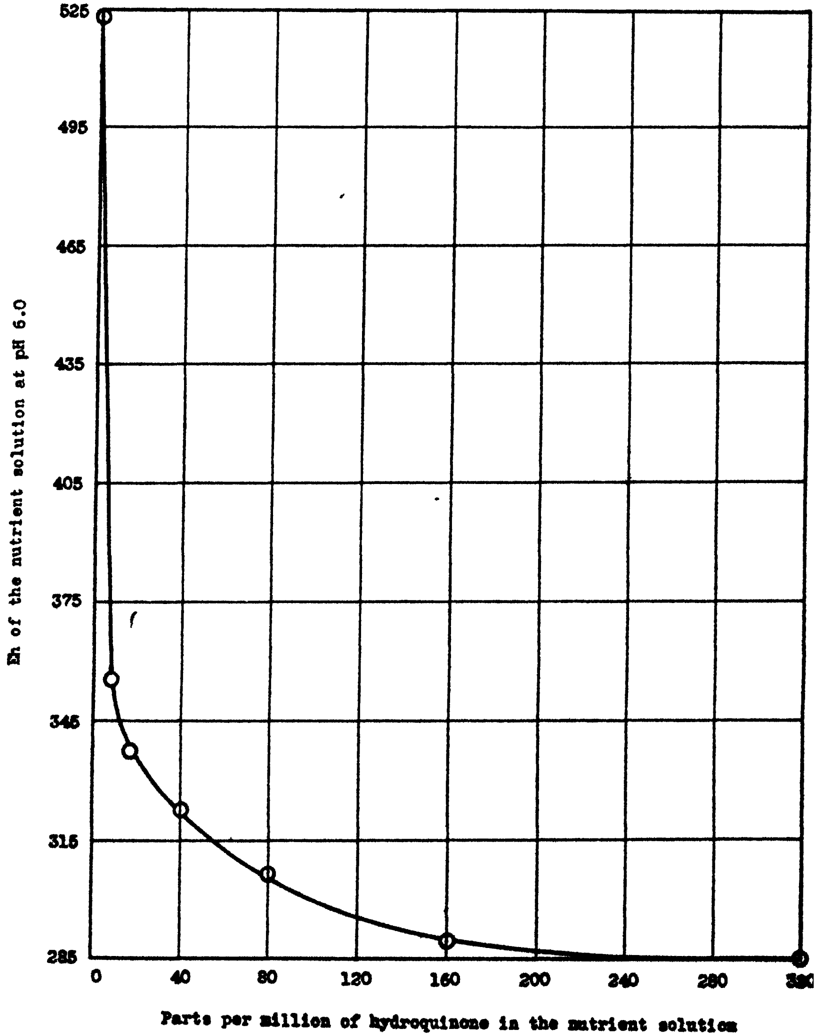

FIG. 1.—The effect of hydroquinone on the Eh value of the nutrient solution.

power to alter the Eh of the solution. Hydroquinone was found to be very suitable in small quantities. The range in Eh of 35 different batches of nutrient solution is shown in Table 1 and Fig. 1. It is evident that the magnitude of the change in Eh decreases rapidly with increasing increments of hydroquinone up to 10 ppm, and that the decrease thereafter is moderately slow.

TABLE 1.—*The Eh value of nutrient solution containing different amounts of hydroquinone.*

Nutrient solution plus	Eh of solution in millivolts at pH 6.0				
	Test 1	Test 2	Test 3	Test 4	Test 5
No hydroquinone	521	520	526	524	524
10 ppm hydroquinone	354	355	357	357	356
20 ppm hydroquinone	336	337	341	340	338
40 ppm hydroquinone	319	324	325	319	323
80 ppm hydroquinone	306	307	308	307	308
160 ppm hydroquinone	294	291	291	290	291
320 ppm hydroquinone	284	281	281	287	285

Thirteen different crop plants were used in studying the effect of Eh on plant growth as follows: Sorghum, sudan grass, corn, sunflower, cotton, tomatoes, vetch, string beans, cowpeas, soybeans, crotalaria, alfalfa, and garden peas.

The aim, during the growth of the plants, was to maintain three cultures at an Eh between 500 and 550 millivolts, which is about normal for most arable Alabama soils, and three cultures between 325 and 350 millivolts, which is 100 to 150 millivolts below the lowest point reached by an arable Alabama soil tested during 1937 (6). Since the Eh of the base nutrient solution was about 525, one set of three cultures was kept between 500 and 550 millivolts simply by passing the nutrient solution through the sand cultures at a rate that would maintain a constant Eh. In the case of the cultures held at an Eh value below 350 millivolts, it was found necessary to start the seedlings with a nutrient solution containing only 15 ppm of hydroquinone (Eh between 330 and 350). When tests of the waste solution showed that the Eh was being raised above 350 millivolts by the plants, either the speed with which the nutrient solution was passed through the sand was increased, or a little more hydroquinone was added. Because of the toxic effect, very few plants could stand more than 15 ppm of hydroquinone in the seedling stage or more than 60 to 70 ppm in later stages; hence in many cases several gallons of solution containing only a small amount of hydroquinone had to be run through the cultures daily to maintain a constant Eh below 350 millivolts. The quantity of nutrient solution passed through an individual culture was at no time less than 6 liters a day.

To preclude the accumulation of salts in the sand, the cultures were flushed daily with 2 liters of distilled water followed immediately by 2 liters of the particular nutrient solution being used on that pot. This procedure caused the plants to be out of contact with the nutrient solution only about 5 minutes. The Eh of the waste nutrient solution escaping from the sand cultures was tested daily and any necessary adjustments made to maintain the desired Eh. All solutions were in equilibrium with the air at all times, thus oxygen was not a limiting factor in the growth of the plants. By the above procedure it is believed that the plant roots were at all times bathed in a solution of desired Eh value and yet were supplied with all the necessary plant food elements including a supply of available oxygen.

RESULTS AND DISCUSSIONS

For the 13 crops tested, no detrimental effects were observed when the Eh of the nutrient solution was lowered from about 525 millivolts to about 325 millivolts (Figs. 2, 3, and 4 and Table 2). Since an Eh value of 325 is roughly 150 millivolts below the Eh reached by

any arable Alabama soil tested during 1937 (6), it appears quite probable that the small variations in oxidation-reduction *potential* observed in arable Alabama soils has little or no effect on plant growth Of course, since potentials only as low as 325 were studied at this time, nothing can be said of the effect of the extremely low potentials reported by Peech and Boynton (2) The fact that a redox potential of 325 has not affected the plants tested does not in any sense infer that changes in factors closely associated with it, such as

FIG 2 Sudan grass grown in pots 1 and 3 at an Eh between 500 and 550 millivolts and in pot 2 at an Eh between 325 and 350 millivolts all at pH 6 0

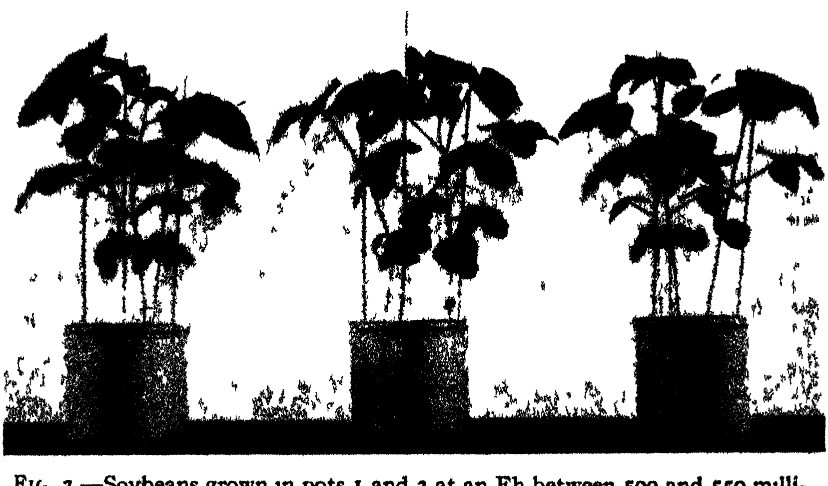

FIG 3 —Soybeans grown in pots 1 and 3 at an Eh between 500 and 550 millivolts and in pot 2 at an Eh between 325 and 350 millivolts, all at pH 6.0.

FIG. 4.—Tomatoes grown in pots 1 and 3 at an Eh between 500 and 550 millivolts and in pot 2 at an Eh between 325 and 350 millivolts, all at pH 6.0.

the lack of available oxygen, reduction, oxidation, toxic substances, etc., will not affect plants. The work of Peech and Boynton (2) and of Bradfield, Batjer, and Oskamp (1) certainly indicates that some factor is affecting plant growth in water-logged soils, but whether

TABLE 2.—*Amounts of plant material produced at different Eh values in constant flow nutrient solution in sand cultures.*

Plants grown in nutrient solution	Dry weight of plants in grams	
	Nutrient solution Eh 525	Nutrient solution Eh 325 to 350
Sudan grass	28.7	27.5
Sorghum	33.5	33.7
Sunflower	37.4	37.5
Corn	37.0	35.5
Cotton	17.1	18.0
Alfalfa	22.0	23.0
Garden peas	7.9	8.0
Crotalaria	23.0	26.0
String beans	7.8	7.3
Soybeans	16.1	16.5
Cowpeas	16.6	17.0
Vetch	6.5	6.0
Tomatoes	64.5	58.5
Total dry weight of plants	318.1	314.5

or not it is strictly the Eh remains to be proved in the case of extremely low potentials. The work of Schreiner and Sullivan (3) indicates that soil oxygen may play an important part.

Single isolated soil Eh values reveal very little regarding the state of oxidation or reduction in a particular soil under field conditions. When the Eh value is obtained it is known that a particular soil at the time of testing had a certain Eh value, but an interpretation cannot be made within narrow limits as regards the state of oxidation or reduction of that soil as compared with some other soil since the kinds, relative amounts, and states of oxidation of the ions causing the resultant potentials are not known. A series of determinations, however, obtained over a period of time on a given soil would be more revealing as regards the state of oxidation or reduction (6).

CONCLUSIONS

A study was undertaken for the purpose of determining the effect of oxidation-reduction *potential*, within certain limits, on plant growth when oxygen was not a limiting factor. Thirteen different crops were tested using sand cultures and constant flow nutrient solutions of different Eh values but of constant nutrient value and in equilibrium with the air. No attempt was made to study changes in the state of oxidation or reduction, or other changes that might accompany changes of Eh in soils. In all tests it is believed that Eh was the only variable present.

The results show that for the plants tested, a change in Eh from about 525 millivolts to about 325 millivolts did not affect plant growth. An Eh of 325 millivolts is approximately 100 to 150 millivolts below the lowest Eh reached by 48 arable Alabama soils tested throughout the year 1937.

Oxidation-reduction potentials below 325 millivolts have not been studied by the method described herein.

LITERATURE CITED

1. BRADFIELD, R., BATJER, L. P., and OSKAMP, J. Soils in relation to fruit growing in New York. Part IV. The significance of oxidation-reduction potentials in evaluating soils for orchard purposes. Cornell Univ. Agr. Exp. Sta. Bul. 592. 1934.
2. PEECH, M., and BOYNTON, D. Soils in relation to fruit growing in New York. Part X. Susceptibility of various New York orchard soils to reduction upon waterlogging. Cornell Univ. Agr. Exp. Sta. Bul. 667. 1937.
3. SCHREINER, O., and SULLIVAN, M. X. Studies in soil oxidation. U. S. D. A. Bur. Soils Bul. 73. 1910.
4. STEPHENSON, R. E., SCHUSTER, C. E., and SPULNIK, J. Oxidation-reduction potentials in orchard soils. Jour. Amer. Soc. Agron., 30:91–96. 1938.
5. STURGIS, M. B. Changes in the oxidation-reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. La. Agr. Exp. Sta. Bul. 271. 1936.
6. VOLK, N. J. Oxidation-reduction potentials of Alabama soils as affected by soil type, soil moisture, cultivation, and vegetative cover. Jour. Amer. Soc. Agron., 31: 1939.

EFFECT OF AVAILABLE PHOSPHORUS IN SOUTHERN SOILS UPON CROP YIELDS[1]

CLARENCE DORMAN AND RUSSELL COLEMAN[2]

FINDING a way to obtain maximum benefit from applied phosphorus has become a major problem in agriculture. This problem is of particular importance to the South where many soils, although very low in dilute acid soluble phosphates, give little crop response when soluble phosphates are applied. Recent investigations (1, 2)[3] have indicated that this lack of crop response is due to a rapid fixation of applied phosphorus into forms which are unavailable to plants. Ford (3) and others (5) have found that calcium, iron, and aluminum are responsible for phosphorus being fixed into an insoluble form.

Phosphorus fixation varies greatly with different soils. Beater (1) found that the quantity of phosphorus fixed is roughly proportional to the amount of clay present. Scarseth and Tidmore (9) report large amounts of phosphorus fixed by soil colloids, and suggest that phosphorus application should be based on the amount of colloids present. They found that an application of 2,000 pounds of superphosphate per acre to a soil with 60% colloid material was equivalent to 300 pounds applied to a soil with 9% colloidal material.

The work of Heck (5) indicates that phosphorus is fixed much more rapidly in some soils than in others; therefore, it seems evident that no general recommendations may be made for phosphorus fertilization. Each soil presents its particular problems and should be treated according to its specific needs. Some southern soils show a definite response to phosphorus while others show very little. Can the phosphate-deficient soils receive enough available phosphorus from light applications, or do they require heavy applications for maximum crop response? Evidently the answer to this question depends upon several factors, namely, the crop grown, the climate, and the nature of the soil. It is the purpose of this study to determine the phosphate requirements of several important southern soils and to suggest a method for recommending phosphate applications.

EXPERIMENTAL PROCEDURE

Both greenhouse and field studies were made on several soil types varying greatly in physical and chemical properties and representing a large number of southern soils.

Greenhouse Study.—Representative samples from the A horizon of Ruston, Orangeburg, and Susquehanna fine sandy loams were used. Four different samples of each soil type, taken from 12 widely separated areas, were removed to the greenhouse, and weighed into 3-gallon pots. The top 3 inches of the soil were removed, and after the fertilizer had been distributed evenly, the soil was replaced

[1]Contribution from the Agronomy Department, Mississippi Agricultural Experiment Station, State College, Miss. Paper No. 15, New Series. Received for publication April 8, 1939.

[2]Acting Director and Agronomist, and Assistant in Soils, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 677.

in the pots, leaving the fertilizer 3 inches beneath the surface. Phosphorus was applied as mono-calcium phosphate, equivalent to 400, 800, and 1,600 pounds of 18% superphosphate. Nitrogen and potash were also applied in most treatments to eliminate them as variables.

The soils in the pots were held at optimum moisture content for two weeks, and at the end of this period available phosphorus was determined by the Truog method (10). Equilibrium between the soil and phosphorus should have been reached within this time, because other investigations (7, 9) have shown that the reaction between a soluble phosphate and the soil is practically instantaneous.

Two crops of sagrain (a grain sorghum) were used to measure crop response. The first crop was planted immediately after the available phosphorus was determined, and the second was planted in the same pots after the first crop was harvested.

Field Study.—Soils obtained from a cotton test previously conducted on 10 different soils, representing eight soil types, were used as a basis for this study. The soils represented are Ruston fine sandy loam, Oktibbeha clay, Grenada silt loam, Savannah very fine sandy loam, Cahaba fine sandy loam, Olivier silt loam, Houston clay loam, and Trinity fine sandy loam. Samples were taken from two plats in each of the 10 soils, one of which had received 400 pounds of 4-8-4 and the other 400 pounds of 4-0-4 per acre for five years. About 20 small samples were taken from the top soil of each plat and after these were mixed thoroughly into one composite sample, available phosphorus was determined on each by the Truog method. The average cotton yields on the 4-8-4 and 4-0-4 plats were calculated and compared with the amount of available phosphorus present.

RESULTS AND DISCUSSION

EFFECT OF AVAILABLE P_2O_5 IN SOIL UPON YIELD OF SAGRAIN

The data in Table 1 show the sagrain yields and available P_2O_5 in pots which had received different phosphate treatments. The untreated pots show a great difference in the fertility of the same soil type taken from different locations, which makes it very difficult to compare the productivity of soil types. It is interesting to observe, however, that Susquehanna fine sandy loam, a very poor agricultural soil, yielded as much sagrain in the greenhouse as Ruston and Orangeburg fine sandy loams, two highly productive soils.

Crop response to phosphorus was similar in 11 of the 12 soils studied in the greenhouse. All of the soils were originally low in available P_2O_5, none having over 6 ppm, and all except one gave an excellent response to phosphorus both when applied alone and when used with nitrogen and potash. Maximum response in almost every case was obtained when an equivalent of 400 pounds of superphosphate per acre was applied with 400 pounds of 4-0-4 fertilizer per acre, and hardly any additional response was obtained when equivalents of 800 and 1,600 pounds of superphosphate per acre were applied with 400 pounds of 4-0-4 per acre.

The results on Susquehanna fine sandy loam (No. 11) show that an increase from 3 to 10 ppm of available P_2O_5 increased the sagrain yield from 13.9 to 28.9 grams, but a further increase in available P_2O_5 failed to increase the yield. The soil containing 10 ppm available

TABLE 1.—*Effect of available P_2O_5 upon the yield of sagrain.*

Soil No.	Observation	Fertilizer treatment* 400 lbs. 4-0 4	400 lbs. superphosphate and 400 lbs. 4-0 4	800 lbs. superphosphate and 400 lbs. 4-0 4	1,600 lbs. superphosphate and 400 lbs. 4-0 4	No fertilizer	800 lbs. superphosphate
	Susquehanna Fine Sandy Loam						
11	Dry weight in grams	13.9	28.9	24.1	26.9	12.6	20.1
	Available P_2O_5 in ppm	3.0	10.0	18.0	42.0	—	—
12	Dry weight in grams	15.6	25.4	24.8	25.6	13.9	20.2
	Available P_2O_5 in ppm	4.0	10.0	19.0	45.0	—	—
13	Dry weight in grams	9.4	13.8	14.7	14.9	6.6	11.5
	Available P_2O_5 in ppm	6.0	17.0	21.0	42.0	—	—
14	Dry weight in grams	20.2	24.4	21.7	20 6	13.6	16.1
	Available P_2O_5 in ppm	5.0	14.0	23.0	45.0	—	—
	Ruston Fine Sandy Loam						
15	Dry weight in grams	14.2	22.6	21.8	21.5	10.8	11.7
	Available P_2O_5 in ppm	2 0	11.0	18.0	42.0	—	—
16	Dry weight in grams	8.0	16.1	13.5	14.6	5.2	9.6
	Available P_2O_5 in ppm	2.0	8.0	12.0	32.0	—	—
17	Dry weight in grams	14.9	17.0	20.6	19.8	10.0	14.5
	Available P_2O_5 in ppm	3.0	8.0	13.0	43.0	—	—
18	Dry weight in grams	21.1	25.1	26.0	27.5	17.2	19.3
	Available P_2O_5 in ppm	3.0	8.0	22.0	35.0	—	—
	Orangeburg Fine Sandy Loam						
19	Dry weight in grams	11.7	15.5	16.5	12.6	8.4	9.9
	Available P_2O_5 in ppm	5.0	18.0	15.0	38.0	—	—
20	Dry weight in grams	19.4	19.1	22.9	19.5	16.5	14.8
	Available P_2O_5 in ppm	4.0	17.0	21.0	43.0	—	—
21	Dry weight in grams	7.3	16.9	17.5	19.4	2.0	11.2
	Available P_2O_5 in ppm	2.0	8.0	11.0	22.0	—	—
22	Dry weight in grams	26.9	31.2	29.8	27.9	16.2	23.0
	Available P_2O_5 in ppm	3.0	21.0	32.0	60.0	—	—

*Phosphorus applied as mono-calcium phosphate equivalent to superphosphate.

P_2O_5 yielded just as much as the one containing 42 ppm. The other three Susquehanna soils showed similar response.

The response of sagrain on Ruston and Orangeburg fine sandy loams was very similar to that obtained on Susquehanna. An increase from 2 to 8 ppm available P_2O_5 in Ruston fine sandy loam (No. 16) increased the sagrain yield from 8 to 16.1 grams, but an additional increase to 32 ppm failed to increase the yield of sagrain. Likewise an increase from 2 to 8 ppm available P_2O_5 in the Orangeburg sandy loam (No. 21) increased the sagrain yield from 7.3 to 16.9 grams, but additional increases in available P_2O_5 failed to increase crop yields. One soil containing only 6 ppm available P_2O_5 did not respond to any phosphate treatment.

The results show that soils with 5 and 6 ppm available P_2O_5 failed to give as much response to phosphate applications as those with only 2 and 3 ppm Phosphorus applications increased the yield of sagrain on every soil except one, but after the available P_2O_5 in the soil had reached 10 or 15 ppm, greater applications of phosphorus failed to increase yields Maximum yields were obtained on many soils with only 16 pounds (8 ppm) available P_2O_5 per acre, which is a lower requirement than most investigators have reported Truog (10) has set the minimum limit of readily available phosphorus at 50 pounds per acre in the plowed layer of the sandy soils of Wisconsin However, he suggested that 20 to 30 pounds may suffice for growing corn in certain sections of the South

EFFECT OF AVAILABLE P_2O_5 IN SOIL UPON YIELD OF COTTON

The data in Table 2 show the available P_2O_5 and cotton yields on 10 different soils which had been treated with 400 pounds of 4 8–4

TABLE 2 —*Effect of available phosphorus upon the yield of cotton*

Soil No	Soil type	Fertilizer treatment 400 lbs per acre	Available P_2O_5 ppm	5-year average yield lbs seed cotton per acre	Increase in yield from phosphorus lbs per acre	pH value
1	Ruston fine sandy loam	4-0-4	3	337		
		4 8 4	6	663	326	6 6
*2	Ruston fine sandy loam	4 0 4	12	574		
		4 8 4		619	45	6 4
3	Olivier silt loam	4 0-4	10	1 076		
		4 8 4	15	1,186	110	5 6
4	Oktibbeha clay	4-0 4	9	543		
		4 8 4	18	613	70	5 6
5	Savannah very fine sandy loam	4 0 4	6	684		
		4 8 4	14	786	102	6 7
6	Savannah very fine sandy loam	4 0 4	38	1,333		
		4 8 4	48	1,341	7	7 5
7	Cahaba fine sandy loam	4-0-4	12	619		
		4 8 4	17	707	88	6 1
8	Grenada silt loam	4-0-4	15	1,318		
		4 8-4	29	1,352	34	7 2
9	Trinity fine sandy loam	4 0-4	60	707		
		4 8 4	85	733	25	8 4
10	Houston clay loam	4-0-4	16	553		
		4-8-4	—	563	10	7.5

*Two years results only

and 400 pounds of 4–0–4 fertilizer for five years. The results show a great difference in the fertility of each soil type. One contained only 3 ppm available phosphorus while another contained 60 ppm in the 4–0–4 plat. Although the reaction of many of the soils was suitable for phosphorus fixation, the available P_2O_5 in every soil was higher in the 4–8–4 plat, which shows a definite residual effect from 160 pounds of P_2O_5 applied over a period of five years. The soils which were originally low in available P_2O_5 gave an excellent response to phosphate applications. Increasing the available P_2O_5 in Ruston fine sandy loam (No. 1) from 3 to 6 ppm increased the cotton yields from 337 to 663 pounds per acre, an increase of 326 pounds. Soils containing from 6 to 15 ppm available P_2O_5 also responded to phosphorus, but not nearly as much as the one containing less available P_2O_5. Phosphorus applied to another Ruston fine sandy loam, very similar to No. 1 but containing 12 ppm available P_2O_5, increased the yield only from 574 to 619 pounds per acre.

Phosphorus applied to Savannah very fine sandy loam (No. 5) increased the available phosphorus from 6 to 14 ppm and increased the cotton yield from 684 to 786 pounds per acre Oktibbeha clay with only 9 ppm available P_2O_5 showed an increased cotton yield from 543 to 613 pounds per acre when the available P_2O_5 was raised to 18 ppm, and Olivier silt loam gave an increase from 1,076 to 1,186 pounds of seed cotton per acre when the available P_2O_5 was increased from 10 to 15 ppm. Increasing the available P_2O_5 in Cahaba fine sandy loam from 12 to 17 ppm increased the cotton yield from 619 to 707 pounds per acre; but soils with available phosphorus higher than 12 to 15 ppm failed to respond to phosphorus treatments. Increasing the available phosphorus in Grenada silt loam from 15 to 29 ppm only increased the yield of cotton from 1,318 to 1,352 pounds per acre, an insignificant increase. Savannah very fine sandy loam (No. 6), very similar in texture and structure to soil sample No. 5 but containing 38 ppm available phosphorus, failed to respond to the phosphate applications, although available P_2O_5 was increased to 48 ppm. Trinity fine sandy loam with 60 ppm available P_2O_5 only gave an increase from 707 to 733 pounds when the available phosphorus was increased to 85 ppm, and phosphate applications to Houston clay loam, containing only 16 ppm available P_2O_5, failed to increase the yield of cotton.

The data show that the soil which contained less than 6 ppm available phosphorus gave an excellent response to applied phosphate, and that soils with less than 15 ppm also responded to phosphorus until this level was reached. However, soils higher in available phosphorus than 15 ppm failed to respond to phosphate applications, although available phosphorus was greatly increased.

Scarseth and Tidmore (8), working with the Black Belt soils of Alabama, found a high degree of correlation between the growth of oats and available phosphorus by the Truog method. They found that soils with less than 30 pounds available P_2O_5 made very poor yields of oats without phosphate fertilization. The data in Tables 1 and 2 show an excellent correlation between crop yields and available P_2O_5 by the Truog method as long as the available P_2O_5 is less than

30 pounds per acre (15 ppm), and they indicate that cotton and sagrain will respond to phosphate applications only on soils containing less than 30 pounds available P_2O_5 per acre.

Probably the most widely used fertilizer for cotton is 4-8-4, and cotton tests show that 4-0-4 is almost as effective on soils with more than 15 ppm of available P_2O_5. In order for the plant to utilize its nutrients most efficiently, there must be a proper balance of the essential elements, and in southern soils 15 ppm available P_2O_5 is probably enough to maintain the proper balance between the limited nitrogen and potassium. Most southern soils are especially deficient in nitrogen, and if greater quantities were added more than 15 ppm available P_2O_5 would probably be required to maintain the balance.

Most southern soils, however, do not contain 30 pounds of available P_2O_5. Eighteen of the 22 soils studied contained less than 30 pounds of available P_2O_5, and most of these gave excellent response to phosphorus It is very important, therefore, that phosphate fertilizer be applied to most southern soils. Phosphate-loving plants may even respond to phosphate treatments on soils high in available P_2O_5, but there is a limit to the amount of available P_2O_5 required for cotton and sagrain.

SUMMARY

Greenhouse studies were made by growing two crops of sagrain on 12 different soils, representing four samples of Susquehanna, Ruston, and Orangeburg fine sandy loams. The available P_2O_5 in each soil, which had received different phosphate treatments, was determined by the Truog method.

Susquehanna fine sandy loam, a poor soil in the field, gave as high yields in the greenhouse as Ruston and Orangeburg fine sandy loams, two excellent agricultural soils.

All of the soils studied in the greenhouse contained less than 6 ppm available P_2O_5, and 11 of the 12 responded to the first phosphate applications, but none responded to heavier applications. Sagrain yielded as well on soils with 10 ppm available P_2O_5 as on those with 40 ppm. Maximum yields were obtained on many soils with only 8 ppm (16 pounds per acre) available P_2O_5.

Field studies were made by growing cotton on 10 different soils for five years. Soil samples were obtained from the 4-8-4 and 4-0-4 treated plats and available P_2O_5 was determined by the Truog method.

The 10 soils varied greatly in their response to phosphorus. Those containing less than 6 ppm available P_2O_5 gave excellent response; those containing from 6 to 15 ppm gave some response; but those containing more than 15 ppm gave very little or no response to phosphorus, although available P_2O_5 was greatly increased by the phosphate application.

Cotton and sagrain failed to respond to phosphate applications on soils containing 15 ppm or more available P_2O_5, which indicates that under southern conditions crops do not require large quantities of phosphorus. Most southern soils do not contain 15 ppm available P_2O_5 and require phosphorus, but applications should not be made

without determining the available P_2O_5 present. It is believed that when nitrogen and potassium are limited and phosphorus fixation is at a minimum, phosphate recommendations for cotton and sorghum may be made on the following basis: Soils containing less than 6 ppm available P_2O_5 require liberal applications, those containing from 6 to 15 ppm require light applications, but those containing more than 15 ppm require very little or no phorphorus.

LITERATURE CITED

1. BEATER, B. E. The measurement of phosphate fixation in soils. Soil Sci., 44:277-290. 1937.
2. BROWN, L. A. A study of phosphorus penetration and availability in soils. Soil Sci., 39:277–287. 1935.
3. FORD, M. C. The nature of phosphate fixation in soils. Jour. Amer. Soc. Agron., 25:134 144. 1933.
4. HECK, A. FLOYD Phosphate fixation and penetration in soils. Soil Sci., 37: 343 356. 1934.
5. ———. A method for determining the capacity of a soil to fix phosphorus in a difficultly available form. Soil Sci., 38:477–482. 1934.
6. ROSZMANN, C. A Retention of phosphorus by soil colloids. Soil Sci., 24:465–474. 1927.
7. SCARSETH, G D. Morphological, greenhouse, and chemical studies of Black Belt soils of Alabama. Ala. Agri. Exp. Sta. Bul. 237 1932.
8. ———, and TIDMORE, J. W. Phosphate fixation by colloids. Jour. Amer. Soc. Agron., 26:138–151. 1934.
9. ———, ———. The fixation of phosphates by clay soils. Jour. Amer. Soc. Agron., 26:152 161. 1934.
10. TRUOG, EMIL. The determination of the readily available phosphorus in soils. Jour. Amer. Soc. Agron., 22:874-882. 1930.

SEED COLOR STUDIES IN BIENNIAL WHITE SWEET CLOVER, *MELILOTUS ALBA*[1]

MATTHEW FOWLDS[2]

SWEET clover is adapted to growth over a wide area. Its value as a forage and soil-improving crop is well recognized. New characters which modify the appearance, quality, or adaptation of the crop are of general interest to growers and plant breeders.

The varieties of sweet clover commonly grown have yellow seed In certain varieties the seed coat may be mottled with a reddish purple pigment. Pale yellow seed is another color variation which the writer has occasionally found ás a mixture in some lots of ordinary sweet clover seed. A single mature plant which produced green seed was discovered by the writer in 1933. This paper presents investigations with green seed, pale yellow seed, and hybrids between these forms and the ordinary yellow-seeded sweet clover.

REVIEW OF LITERATURE

Coe and Martin (3),[3] working with sweet clover seed, reported that a well-developed "light line" was formed in the outer region of the Malpighian layer just below the base of the cones. After soaking the seed in water containing stains, they found that the light line in hard seed was the region which prevented the absorption of water. In permeable seeds, canals were found to cross the light line thus forming passageways through which water entered the seed. In histological studies Stevenson (4) found that the cells were less closely packed in permeable areas and that penetration was by way of the middle lamella.

Stevenson (4) investigated the inheritance of mottling in *Melilotus alba*. The mottled condition of the seed coat was found to be dependent upon a single factor pair and was inherited as a dominant character when other factors were favorable for the development of pigment. The appearance of the seed coat was not always an accurate basis for classification since the seed may be potentially mottled and still show no trace of the pigment. The same plant may produce non-mottled seed and seed varying greatly in the degree of mottling. Since mottling occurs in the seed coat which is maternal tissue, the degree of mottling appears to be influenced by other factors which have not been determined. He states that the pigment involved in the mottling had all the general properties of anthocyanins and was located in the lower part of the Malpighian cells.

A type of sweet clover that differed widely from the common type has been described by Kirk (2). The plants were profusely branched from the crown and the stems were exceptionally fine. In a cross between the dwarf-branching type and tall sweet clover, Stevenson (4) found that the dwarf branching habit of growth was dependent for its expression upon a single factor difference. The common type was completely dominant to the dwarf-branching type.

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[3]Figures in parenthesis refer to "Literature Cited", p. 686.

MATERIALS

The material used in the study of green seed color was furnished by a single plant discovered in September 1933. This plant was found by a roadside at some distance from other sweet clover plants. A natural hybrid between the green-seeded form and a yellow-seeded plant was used in a study of the mode of inheritance of the green color.

Material for the study of pale yellow seed color was obtained from commercial lots of sweet clover. It was observed that a trace of pale yellow seed occurred in occasional lots of sweet clover seed examined for purity in the seed laboratory. The selections of pale yellow seed were made from different lots of sweet clover extending over a period of several years. A natural hybrid between pale yellow and yellow was used in the study of inheritance of the pale yellow color.

NATURE AND LOCATION OF COLOR IN THE SEED

The seed coat in sweet clover seed was found to be somewhat translucent. For this reason the embryo beneath the seed coat may influence the observed seed color. In order to determine the actual color in seed coat and embryo, it was necessary to remove the seed coat, but it was difficult to do this with dry seed. In this study scarified seed was placed upon moist blotting paper. After the seed had imbibed water the seed coat was easily removed and the color of each part could then be determined.

The normal color of well-matured sweet clover seed has been described as golden yellow. After removing the seed coat it was observed that seed coat and embryo of yellow seed were both yellow. Likewise in green seed both were green. The pale yellow seed was found to have a white seed coat and a yellow embryo

The seed produced by a green female parent when pollinated by a yellow-seeded plant was pale green. The maternal seed coat of this F_1 seed was green as expected, but the embryo was yellow. The seed produced by this hybrid segregated for yellow and pale green. The pale green segregate was found to have a yellow seed coat and a green embryo, hence the color arrangement found in the pale green F_1 was reversed in the pale green F_2 segregate. The two forms of pale green seed could not be distinguished from each other by inspection, but they could readily be identified after the seed coat was removed and each part examined separately. The influence of the color combinations in seed coat and embryo upon the observed color of the seed is shown in Table 1.

TABLE 1.—*The location of color in seed coat and embryo in different genotypes of sweet clover seed and the relation of this arrangement to the observed seed color.*

Class	Seed coat	Embryo	Observed seed color	Remarks
1	Yellow (YY)	Yellow (YY)	Yellow	Common yellow seed
2	Yellow (Yy)	Yellow (YY)	Yellow	Homozygous yellow segregate
3	Yellow (Yy)	Yellow (Yy)	Yellow	Heterozygous yellow segregate
4	Green (yy)	Green (yy)	Green	Normal green seed
5	Yellow (Yy)	Green (yy)	Pale green	Homozygous green segrate
6	Green (yy)	Yellow (Yy)	Pale green	F_1 hybrid green $\times$ yellow
7	Yellow (YY)	Yellow (Yy)	Yellow	F_1 hybrid yellow $\times$ green*

*This class has not been observed.

Although coloration of seed coat and embryo may appear alike to the eye, the pigments show a different reaction to water at temperatures favorable for germination. Scarified seed of any type having a colored seed coat liberates a greenish yellow stain when placed upon a moist blotter The white seed coats of pale yellow seed liberate no stain under similar conditions. Hard seed of any type fails to liberate the soluble pigment as long as water does not penetrate the seed coat. Excised embryos were placed upon moist blotting paper These absorbed water and began to grow without liberating any stain. The results show that colored seed coats contain a soluble pigment and the white seed coats are free from such pigment.

According to Coe and Martin (3), the light line is the impermeable layer in sweet clover seed, while the outer layer of the seed coat is readily permeable to water Since the embryo does not liberate any color, the soluble pigment should be located in the seed coat beneath the light line Stevenson (4) has shown that the antocyanin pigment which gives rise to the mottled condition in certain types of sweet clover seed is located in the lower part of the Malpighian cells

NATURAL CROSSING IN THE GREEN-SEEDED SELECTION

Green seed from the plant discovered in 1933 was sown in the greenhouse The plants were grown under electric light during the winter and a crop of selfed seed was produced After harvesting this seed the plants were transplanted to the field and, late in the season, one of them blossomed for the second time where it was exposed to cross-pollination with ordinary sweet clover. Progenies were grown from selfed seed and from open-pollinated seed in subsequent generations. The results from each line will be presented separately.

Selfed seed was sown in the greenhouse. About 100 seedlings from this seed were transplanted to a field plat in June 1934. When the seed from this plat was threshed in 1935, two shades of green were recognized but the significance of the color variation was not fully appreciated at the time A part of the seed was sown on a small plat the following spring and the next crop harvested in 1937. The seed obtained from the 1937 crop was a mixture of green, pale green, and yellow. About 30% of the seed was found in the yellow class A trace of mottling also occurred in the yellow and in the pale green portion of the seed.

After observing this segregation for seed color a sample of reserve seed from the 1935 crop was re-examined. The seed was separated into green and pale green classes. About 10% of the seed was found in the pale green class. The seed coats were removed from a few seeds in each class by the method previously described. The seed coats in each class of seed were found to be green, but the embryo in the pale green class was yellow. As shown in Table 1, this type of pale green seed is the F_1 hybrid produced by a green female parent.

Because volunteer sweet clover seedlings were killed by drought the previous season, only one source of pollen carrying the factor for yellow seed was in evidence at the time the green-seeded plants were in blossom. This source was a small plat containing a tall yellow-

seeded selection segregating for mottled seed. The mottled seed found in the hybrid portion of the 1937 crop is also a good indication that this plat was the true source of the foreign pollen.

Evidence that crossing took place in 1935 when the plants were in blossom was also shown by an important plant character. The green-seeded plants grown in 1935 were of medium height and produced numerous leafy stems. This dwarf branching growth habit resembles the habit described by Kirk (2) for the Alpha variety. The next crop grown in 1937 from the 1935 seed was a mixture of tall and dwarf plants Stevenson (4) found that the common type of growth is completely dominant to the dwarf type. The yellow and the pale green seeds which were found in the 1937 crop were produced by these tall hybrid plants.

Although the hybrids comprised about 10% of the population, they produced approximately 40% of the seed harvested from the plat. This difference in seed production per plant is due in part to the difference in size of plant and to the natural tendency of tall plants to overshadow the dwarf ones growing near them The results show that sweet clover variteies intercross readily when grown near each other If sweet clover selections are to be kept pure, it will apparently be necessary to have the seed plat well isolated from other varieties.

MOTTLING IN THE GREEN-SEEDED SELECTION

A number of the mottled pale green seed which were found in the 1937 crop were separated for examination The seed coat was found to be yellow and the embryo green; hence these must have been pale green segregates from the tall hybrid plants which were found in that crop. The mottling therefore must have developed in the yellow seed coat in conjunction with the yellow color.

Some of the mottled pale green seeds were sown in the greenhouse in October 1937 and plants grown during the winter. The plants produced normal green seed as expected from this genotype. All of the seed produced by one plant was distinctly mottled. Another plant produced seed without a trace of mottling The others were intermediate in type of mottling In this seed the pigment for mottling has developed in the green seed coat in conjunction with the green color. Stevenson (4) has studied the inheritance of mottling in a variety having yellow seed. From the limited observations in this experiment, mottling appears to follow the same tendencies in green seed that have been determined for it in yellow seed.

INHERITANCE OF THE GREEN SEED COLOR

The open-pollinated green seed produced by a single plant in 1934 was sown in the greenhouse. The plants were grown during the winter but they failed to blossom until the following summer When the seed was mature, it was found that one plant was a hybrid producing yellow and pale green seed. The seed was separated into color classes. The yellow class contained 1,210 and the pale green class 458 seeds. The segregation was tested for goodness of fit to a 3:1 ratio by means

of the X^2 distribution and a X^2 of 5.374 was obtained. For one degree of freedom, this corresponds to a P value of between 0.01 and 0.02 in Fisher's (1) table. A deviation as great as the observed could be expected in 1 to 2% of the trials on the basis of random sampling. Although beyond the limit usually accepted as significant, the results indicate a 3:1 ratio.

An F_2 progeny was grown from each class of seed. The seed was sown in the greenhouse and the plants were transplanted to the field in June, 1936. The plants grown from pale green seed were set adjacent to a plat of yellow-seeded sweet clover. The plants grown from yellow seed were set in a single row on the border of a soybean plat and were spaced about 1 foot apart The plants were all grown to maturity without protection from pollinating insects.

When the plants reached a suitable stage of maturity in 1937, the individual plants were cut, tied into bundles, and placed on the ground to dry. The seed was threshed by hand, placed in envelopes and removed to the laboratory to be cleaned and graded previous to classification.

The plat grown from pale green seed contained 31 plants. Since the plants were exposed to cross-pollination the new seed crop was mixed to some extent with pale green F_1 hybrid seed. Disregarding this hybrid seed, all of the plants bred true for green seed color. The pale green type of seed from which the plants were grown has not appeared in the progeny This class of seed is therefore only a transitional stage in hybrids between green and yellow. The results show that the green color is recessive to yellow

In the plat grown from yellow seed, several stunted plants failed to produce seed and were discarded. Eighty-four plants were available for classification. Of these, 46 segregated for yellow and pale green seed and 38 bred true for the yellow color. On the basis of a 2:1 ratio, the expected numbers were 56 and 28, respectively.

A random sample of seed was taken from each segregating population. Discolored and broken seeds were removed from the sample and discarded. The sample was then separated into yellow and pale green classes The number of seed in each class was determined and the X^2 value for each population on the basis of a 3:1 ratio was calculated. The results are presented in Table 2.

Inspection of the data recorded in Table 2 shows that 31 progenies have a X^2 value under 3.841. This is designated as the 5% point in Fisher's table. Nine additional progenies lie within the 1% point. Six progenies lie beyond the 1% point and these indicate a wide departure from the expected values. From the merged data a X^2 of .8187 was obtained. The small value of this X^2 shows that the plus and minus variations have nearly cancelled each other. The data in Table 2 also show that one progeny is a perfect fit, 21 progenies have an excess of yellow, and 24 an excess of pale green. This type of distribution indicates that there is no persisting bias in favor of one class over the other.

TABLE 2.—*Classification of yellow and pale green seed in 46 segregating F_2 progenies from a natural cross, green×yellow, and the X^2 value for each progeny on the basis of a 3:1 ratio.*

Yellow seed	Pale green seed	X^2	Yellow seed	Pale green seed	X^2
524	225	10.175	371	127	0.066
667	189	3.894	548	168	0.901
650	252	4.152	617	184	1.758
620	209	0.019	630	170	6.000
587	236	5.929	623	221	0.631
602	213	0.559	679	278	8.368
634	192	1.359	746	257	0.207
604	237	4.537	786	287	1.747
595	242	6.834	639	171	6.533
757	281	2.375	732	252	0.195
395	93	9 191	454	199	10 438
607	185	1.138	802	219	6.864
548	199	1.071	561	186	0.004
589	165	3.906	572	199	0.270
568	177	0.612	567	182	0.196
560	165	1.942	646	242	2.402
697	267	3.739	637	206	0.142
573	183	0.253	283	81	1.465
573	180	0.482	202	75	0.636
359	135	1.427	344	134	2.345
617	177	3 104	225	84	0.786
815	224	6 560	380	157	5.140
393	118	0.992	207	69	0.000
Totals			25,785	8,692	0.8187

Another test for goodness of fit was made by comparing the observed distribution of X^2 values with the expected frequencies. These data are shown in Table 3.

TABLE 3.—*Test of agreement of the observed distribution of X^2 values with expected frequencies in 46 segregating F_2 progenies.*

X^2	P	C	O	O−C	$(O-C)^2$	$\frac{(O-C)^2}{C}$
0.0000	1.00	0.46	1			
0.0002	0 99	0.46				
0.0006	0.98	1.38	} 2	-2.60	6.76	1.470
0.0039	0.95	2 30	1			
0.0158	0.90	4.60	1	−3.60	12.96	2.817
0.0642	0.80	4.60	2	−2.60	6.76	1.470
0.148	0.70	9.20	5	−4.20	17.64	1.917
0.455	0.50	9.20	9	−0.20	0.04	0.004
1.074	0.30	4.60	4	−0.60	0.36	0.078
1.642	0.20	4.60	6	1.40	1.96	0.426
2.706	0.10	2.30	2			
3.841	0.05	1.38	5			
5.412	0.02	0.46	4 } 17	12.40	153.76	33.426
6.635	0.01	0.46	6			

$X^2 = 41.608$

From the data recorded in Table 3, a X^2 of 41.608 was obtained. For six degrees of freedom the corresponding P value is very small,

hence a deviation as great as this would not be expected on the basis of random sampling. The small value of P indicates a significant departure from the expected distribution on the basis of a 3:1 ratio. The big disturbing factor is the group of 17 progenies having high X^2 values. The other 29 progenies show a reasonably close fit to the expected distribution.

It is desirable in this connection to re-examine the material and the method of handling it in order to find if possible any disturbing factors which would explain this deviation. In several progenies difficulty was experienced in classifying seed of uneven maturity. Immature yellow seed which failed to develop beyond the green stage could not be distinguished with certainty from the green genotype. Errors in classifying samples of this type will result in high X^2 values.

Previous experience has shown that extensive crossing will occur between different types of sweet clover. Thirty-eight plants producing yellow seed were growing in the same plat with the segregating plants These would increase the amount of available pollen carrying the factor for yellow seed Two other plats of sweet clover, one green-seeded and one yellow-seeded, were growing nearby. Perhaps the available pollen was about equally divided between the two types, but the manner of its distribution to individual progenies by insect carriers is not known.

When due allowance is made for the disturbing factors in connection with pollination and for errors in sampling and in classifying the seed, it is thought that the evidence against the assumption of a 3:1 ratio is not convincing. Modifying factors which have not been determined in this study may account for part of the deviation from expected numbers Observations made upon well-matured seed from selfed plants and data from the next generation would be desirable before reaching final conclusions.

INHERITANCE OF THE PALE YELLOW SEED COLOR

Pale yellow seed selected from commercial lots of sweet clover were sown in the field at different times as seed from this source became available. Plants grown from the selected pale yellow seed usually produced a seed crop of the ordinary yellow color, but an occasional plant was found that produced pale yellow seed. Since the original plants producing the pale yellow seed were grown among ordinary sweet clover plants, extensive cross-pollination was to be expected. Natural crossing would account for the small number of true breeding plants when these are grown from this source of seed.

In October 1933, pale yellow seed from a selected plant was sown in the greenhouse. The plants were grown under electric light and selfed seeds were matured during the winter. This seed was found to come true for the pale yellow color. A part of the seed was used to grow another generation in the greenhouse. From the plants continued in the greenhouse where crossing with other types was prevented, a true breeding line was readily established. A part of the selfed seed was also sown in the field. Whenever a new generation was grown from seed which matured in the field, only a small portion of the plants were found to produce seed of the pale yellow color.

A field-grown seedling was removed to the greenhouse in November 1936 and a crop of selfed seed was produced the following spring. The seed was found to be the ordinary yellow color. Evidently this plant was grown from a cross-pollinated seed. Some of the selfed seed was sown in a field row in May 1937. In an effort to obtain selfed seed, cloth bags were placed over branches on a number of plants when they were ready to blossom in 1938. Seed was obtained from nine plants. Of these, seven produced yellow seed and two produced pale yellow seed. Definite conclusions on the mode of inheritance should not be based on such a small number of plants, but the results suggest a 3:1 ratio. The pale yellow color was recessive to yellow.

In February 1938, a green-seeded plant was pollinated with pollen from a plant of the pale yellow type. Both of the parents were selected from selfed lines. The contrasting characters entering this cross were green vs. yellow embryo and green vs. white seed coat color. Hybrid seedlings were grown in the field during the summer and nine of the plants were removed to the greenhouse in November. Selfed seed was obtained from these in March 1939. The seed produced by this F_1 hybrid segregated for green and yellow embryo color as expected, but the seed coat was yellow. The results indicate that complementary factors are necessary for the expression of color in the seed coat. Perhaps the pale yellow type carries the recessive allelomorph of a basic factor for the production of seed coat pigment and a dominant factor for the determination of yellow color. Data from later generations will be required before the mode of inheritance can be fully determined.

SUMMARY

The seed coat in sweet clover seed is usually somewhat translucent. Because of this characteristic, color in the embryo may exert an influence upon the observed seed color.

Two forms of sweet clover, each distinguished by its seed color, have been described. In one form the seed coat and embryo are both green; in the other the seed coat is white and the embryo is yellow.

A pale green seed color which is represented by two distinct forms has been observed in a hybrid between green and yellow. These forms of pale green seed failed to breed true in the next generation.

A mottled condition in the seed coat of a yellow-seeded variety has previously been investigated. In a hybrid between yellow-mottled and green, a segregate has been found which has the mottled condition combined with a green seed coat.

The green seed color is inherited as a recessive to yellow and its determination appears to be dependent upon one main factor pair. The pale yellow seed color is also recessive to yellow.

In a cross between the factors for green seed coat and the white seed coat of pale yellow seed, the F_1 hybrid produced seed with a yellow seed coat. The expression of color in the seed coat appears to be dependent upon complementary factors.

Cross-pollination has occurred freely between the different varieties observed in this study. The crop of seed harvested from a small plat of green-seeded plants showed 10% of cross-pollination when

grown at a distance of 200 feet from a small group of yellow-seeded plants. If sweet clover selections are to be kept pure, the seed plat should be well isolated from other varieties.

LITERATURE CITED

1. FISHER, R A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 5. 1934
2. KIRK, L. E. Alpha sweet clover Univ. of Sask. Agr. Ext. Bul. 45. 1929.
3. COE, H. S., and MARTIN, J N. Structure and chemical nature of the seed coat and its relation to impermeable seeds of sweet clover. U. S D. A Bul. 844:26-35. 1920.
4. STEVENSON, T. M Sweet clover studies on habit of growth, seed pigmentation and permeability of the seed coat. Sci Agr, 17:627-645. 1937

INFLUENCE OF LOW TEMPERATURE TREATMENTS ON THE GERMINATION OF SEEDS OF SWEET CLOVER AND SMOOTH VETCH[1]

L. E. Dunn[2]

GERMINATION percentages of sweet clover (*Melilotus alba* Desr.) and of smooth vetch (*Vicia villosa* Roth.) seed samples are reduced more or less by the presence of hard seeds, that is, seeds with coats impermeable to water. The hard seed content of sweet clover seed samples grown in western Oregon is often more than 45%, while that of smooth vetch seed samples is often more than 15%. Experiments were designed to find the influence of various low temperature treatments on the softening of hard seeds and on the germination of seed samples of sweet clover and smooth vetch.

REVIEW OF LITERATURE

A number of workers, including Harrington (1),[3] Helgeson (3), Jones (4), Leggatt (5), Lute (6), Midgley (7), Schmidt (9), and Whitcomb (10), have studied the influence of various storage conditions and storage in the soil on the softening of hard seeds of cultivated legumes. The results indicate that when seedings are made in the spring nearly all hard seeds of alfalfa and hairy vetch will germinate and produce plants during the first season. The majority of the hard seeds of red clover and sweet clover will not germinate until the second season after the seeds have passed the winter in the soil. In case of red clover many of the hard seeds which become permeable during the winter do not produce plants because of being killed by the freezing weather of winter. Hard seeds of alfalfa and hairy vetch do not stand freezing readily after they have become permeable. Freezing weather is quite effective in the softening of hard seeds especially when the seeds are moist as they are in the soil.

Harrington (2) and Morinaga (8) have conducted experiments which show that the germination of some seeds are favored by favorable temperature alternations. Seeds of Bermuda grass, Canada bluegrass, cat-tail, Kentucky bluegrass, and orchard grass are examples of seeds favored by alternating temperatures.

As a result of these investigations, it was believed that a low temperature treatment might be found which would cause seed samples to give higher germination percentages than samples which had been stored dry at room temperature.

MATERIALS AND METHODS

Samples of locally grown sweet clover and smooth vetch seed were selected for carrying out the experiments. The various samples were given moist and dry treatments under the following storage conditions: (a) Room temperature aver-

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[3]Figures in parenthesis refer to "Literature Cited", p. 694.

age 22° C, ranging from 17° to 27°; (b) 5° C in a low temperature storage room, with a range from 2° to 10° C; (c) –10° C in a low temperature storage room, with a range from –8° to –12° C; (d) –10° C for 1 week followed by a continuous storage at 5° C; (e) alternation –10° C 1 week, 5° C 1 week; and (f) alternation –10° C 1 week, 22° C 1 week.

Storage periods ranged from 1 to 10 months. Following a treatment period for a sample, dead seeds and seeds which had produced radicles more than 1 cm in length during storage were discarded. For sweet clover, these seeds were removed by placing the treated sample in a beaker of water and decanting them off. The remainder of the sample was tested for germination.

Germination conditions consisted of holding the seeds on moist paper toweling in Petri dishes at room temperature. The period of a germination test was 14 days. After the first 7 days those seeds which had germinated were counted and removed. In case of sweet clover, seeds which had produced radicles with root hairs, elongated hypocotyls, and green cotyledonary leaves were considered to have germinated. In case of smooth vetch, seeds which had produced radicles with root hairs and plumules with green leaves were considered to have germinated. Hard seeds included seeds which had not swollen and which had not germinated during the germination test. Germination and hard seed percentages were based on the original number of seeds in a sample as 100% In moist treatments where freezing temperatures were used, the envelopes with their samples were placed in water for 30 minutes and then allowed to drain just before storage. The seeds did not appear to be swollen at the beginning of the low temperature storage.

In case of moist treatments 1 and 6, where a temperature of 22° C was used either part or all of the time, a single sample of 1,000 seeds was used for each treatment and for all periods of time within that treatment. The samples were held on moist blotters in Petri dishes. In case of treatment 1 in which the seeds were kept continuously at 22° C, the dish was opened once each week and the germinated seeds were counted and removed. For treatment 6 in which the sample was held at 22° C every other week, germinated and dead seeds were counted and removed at the close of the 22° C interval. For dry treatments 1 and 6, samples were held in paper toweling envelopes.

In one of the experiments with smooth vetch, hard seeds were used for treatments 1 to 6, inclusive. These seeds were selected by picking the impermeable black seeds from seeds of the original lot which had been soaked for 30 hours at room temperature. During this period of soaking, permeable seeds swelled to more than twice their normal size and turned from black to a light or yellow brown color. At the close of a treatment for a sample, it was placed under germination conditions for 14 days. Seeds which had become permeable were recorded. In all cases hard seeds which had become permeable germinated normally when they were not frozen after taking up water.

EXPERIMENTAL RESULTS

RESULTS WITH SWEET CLOVER

The various treatments and the results are given in Tables 1 and 2. In all cases moist storage treatments were harmful to germination. Similar dry storage treatments had no influence on germination. The various moist and dry storage treatments were observed to have no significant influence on the softening of hard seeds.

TABLE 1.—*Influence of various moist storage treatments on the germination and the softening of seeds of sweet clover.*

Period of treatment	Treatments†											
	No 1, 22° C		No 2, 5° C		No 3, −10° C		No 4, −10° C 1 week, 5° C continuous		No 5, −10° C 1 week, 5° C 1 week		No 6, −10° C 1 week; 22° C 1 week	
	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard tion, %	Germination, %	Hard seed, %
Lot A												
0 (check)	45	51	—	—	—	—	—	—	—	—	—	—
1 week	46	50	45	55	57	41	—	—	—	—	—	—
2 weeks	0	50	20	52	54	44	44	48	40	53	2	55
1 month	0	50	18	36	41	55	14	34	12	50	3	51
2 months	3	47	0	32	12	51	0	27	4	50	1	44
4 months	1	46	0	33	24	44	2	26	3	51	0	44
6 months	2	42	1	27	4	41	0	23	0	44	0	41
Lot B												
0 (check)	37	62	—	—	—	—	—	—	—	—	—	—
2 weeks	1	60	36	62	43	56	41	64	38	61	0	64
1 month	0	60	1	63	32	61	2	62	3	58	1	63
2 months	0	59	0	58	24	63	1	62	2	58	0	63
4 months	0	57	0	54	20	57	0	59	0	57	1	62
6 months	0	54	0	62	8	54	0	61	1	52	1	61
8 months	0	53	1	53	0	46	0	53	0	51	0	60
10 months	0	53	0	62	0	55	0	51	0	60	0	59

*As a check against moist storage, seed samples were given similar treatments under dry storage conditions In all cases the storage treatment had no influence on the percentage germination and the softening of hard seeds

†In case of treatments 1 and 6, samples of 1,000 seeds each were used For all other treatments samples of 300 seeds each were used

TABLE 2.—*Influence of various storage c. nditions on the germination and softening of seeds of sweet clover.*

Period of treatment	Treatments: 22° C, dry storage, samples of 300 seeds each		22° C, moist storage in Petri dishes, samples of 1,000 seeds each		5° C, dry storage, samples of 300 seeds each		5° C, moist storage in open paper towels, samples of 300 seeds each		5° C, moist storage in Petri dishes, samples of 300 seeds each		5° C, moist stoarge in open paper towels, samples of 3,000 seeds each	
	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %	Germination, %	Hard seed, %
Lot A, Threshed Seed from Western Oregon, Seed 1 Year in Age												
0 (check)..	54	42	—	—	—	—	—	—	—	—	—	—
1 month ..	46	50	0	42	47	47	1	42	1	44	0	49
2 months..	52	48	0	42	46	48	0	47	0	45	0	47
4 months..	43	41	0	41	51	44	0	43	0	47	0	46
6 months..	52	46	0	40	55	44	0	43	0	45	0	44
8 months..	58	42	0	40	42	48	0	42	—	—	0	45
10 months..	46	53	0	40	46	51	0	47	—	—	0	41
Lot B, Threshed Seed from Western Oregon												
0 (check)..	37	62	—	—	—	—	—	—	—	—	—	—
1 month. .	38	62	0	60	33	65	1	63	1	61	0	57
2 months.	38	59	0	59	32	67	0	58	1	67	0	61
4 months..	33	65	0	57	44	56	0	54	0	46	0	55
6 months.	41	57	0	54	35	64	0	62	0	49	0	54
8 months.	37	61	0	53	34	64	0	53	—	—	0	61
10 months..	37	63	0	53	37	62	0	62	—	—	0	50
Lot C, Hand-hulled Seed from Western Oregon												
0 (check)..	9	90	—	—	—	—	—	—	—	—	—	—
1 month...	8	92	1	88	11	89	0	88	—	—	—	—
2 months..	11	89	0	87	12	87	0	84	—	—	—	—
4 months..	9	91	0	86	12	88	0	77	—	—	—	—
6 months..	10	89	0	86	14	86	0	85	—	—	—	—
8 months..	12	88	0	86	12	87	0	75	—	—	—	—
10 months..	8	91	0	86	10	90	0	79	—	—	—	—

In the moist treatments many permeable seeds germinated in storage, and very few hard seeds became permeable. Therefore, the tests which followed the storage treatments gave very low germination percentages. In most storage at 22° C, permeable seeds germinated within the first week. After intervals of 1 and 2 months in moist storage at 5° C, permeable seeds had produced radicles of approximately 1 and 2 cm in length, respectively. After periods of 4 months nearly all of the radicles were dead or partially decayed. In case of samples of 3,000 seeds each which were held in moist storage at 5° C, the seeds had weak radicles after 1 and 2 month intervals. For intervals longer than this nearly all radicles were dead. For these treatments above freezing, the small number of hard seeds which had become permeable produced healthy radicles and hypocotyls.

After samples were removed from the −10° C storage treatment, it was observed that permeable seeds were swollen. These samples gave low germination percentages. Apparently the permeable seeds had taken up enough water at the beginning of storage to be injured to some extent by freezing. Hard seeds were not injured by freezing.

At the beginning of the experiments, it was believed that under moist storage slightly above freezing enough water may enter some of the hard seeds to permit a normal slow growth of their embryos at this low temperature The growing embryos in turn may finally injure the surrounding seed coats so that enough water could enter to permit a normal germination at 22° C. No results were obtained to support this concept.

RESULTS WITH SMOOTH VETCH

The results reported in Table 3 show that all moist storage treatments were harmful to the germination of seed samples of smooth vetch. Dry storage of the seed samples under the same treatments had no influence on germination. In case of moist storage at 22° C, permeable seeds germinated during the first week. In case of moist storage at 5° C, permeable seeds produced radicles over 1 cm in length in periods ranging from 2 to 4 weeks. Since seeds which had produced radicles more than 1 cm in length in storage were not counted as part of the germination of samples, germination percentages for the moist treated samples are very low. In case of the moist storage at −10° C, permeable seeds did not appear to be swollen at the time they were placed at this temperature. When these samples were removed and placed under germination conditions, the permeable seeds swelled to a marked extent and then decayed. Apparently enough water had entered the seeds previous to storage so that they were killed by the freezing temperature. Those seeds which germinated after the freezing periods probably were hard seeds which had become permeable in storage.

The moist storage treatments given in Table 3 appeared to cause some softening of hard seeds. The results given in Table 4 show that all the moist treatments were effective in causing a softening of hard seeds. There were marked variations in the impermeability of the hard seeds. In case of moist storage at 22° C, some of the hard seeds became permeable within 1 month, while others were still imperme-

TABLE 3.—*Influence of various storage treatments on the germination and the softening of seeds of smooth vetch.*

Periods of treatment	Treatment*					
	No. 1, 22° C		No. 2, 5° C		No. 3, −10° C	
	Germination %	Hard seed %	Germination %	Hard seed %	Germination %	Hard seed %
	Moist Storage in Paper Towels					
0	82	15	—	—	—	—
2 weeks	4	11	27	18	8	17
1 month	0	11	2	16	1	16
2 months	1	10	0	18	2	12
4 months	1	10	1	15	1	13
6 months	1	10	2	13	2	10
	Dry Storage in Paper Towels					
0	82	15	—	—	—	—
2 weeks	78	17	78	16	80	17
1 month	80	17	75	16	80	16
2 months	75	20	84	15	81	17
4 months	84	14	83	12	81	16
6 months	85	13	85	10	78	16

*In case of treatment 1 in moist storage, a single sample of 1,000 seeds was used for all treatment periods. For treatments 2 and 3 a sample of 300 seeds each was provided for each period.

able after 6 months. When hard seeds became permeable under these conditions, they first swelled and turned to a lighter color and then germinated. With the possible exception of moist storage at 5° C, moist storage at room temperature was as effective as any other treatment in causing a softening of hard seeds.

TABLE 4.—*Influence of various moist storage treatments on the softening of hard seeds of smooth vetch.*

Treatments	Periods of treatments in moist towels and percentages of hard seeds which became permeable after*					
	0	2 weeks	1 month	2 months	4 months	6 months
No. 1, 22° C	0	32	51	54	63	68
No. 2, 5° C	0	—	41	52	71	96
No. 3, −10° C	0	—	39	51	64	82
No. 4, −10° C 1 week and then 5° C continuous	0	—	64	65	72	95
No. 5, alternation −10° C 1 week; 5° C 1 week	0	—	36	62	70	78
No. 6, alternation −10° C 1 week; 22° C 1 week	0	24	62	57	72	83

*For treatment 1, a sample of 200 hard seeds was used for all periods. This was because the sample did not have to be removed from its regular storage treatment for germination conditions to be provided. Hard seeds counts for a given period were taken 2 weeks after the close of the period so that results would be consistent with counts for other treatments. For all other treatments, a sample of 200 hard seeds was provided for each period.

An initial freezing period of $-10°$ C for 1 week, treatment 4, appeared to hasten the softening of a portion of the hard seeds when held moist at $5°$ C. However, by comparison with treatment 2, the initial freezing did not appear to influence the total number of hard seeds which had become permeable after 4 months storage.

In case of the $-10°$ C moist storage, hard seeds were soaked in water 30 minutes just previous to the low temperature storage. The hard seeds did not take up enough moisture to be injured by freezing. Seeds which had become permeable at $-10°$ C germinated normally when germination conditions were provided. In case of the temperature alternations, seeds which had become permable and which had swollen at the higher temperature were killed by the freezing temperature.

After 6 months moist storage under the various conditions only approximately 20% of the original seeds were still impermeable in selected 200 hard seed samples. These experiments would indicate that probably the majority of the hard seeds of smooth vetch would germinate and produce plants the first 2 or 3 months after planting. Probably only a very small percentage of the hard seeds would be left in the soil a year after planting.

SUMMARY

A number of experiments were conducted with locally-grown seed samples of sweet clover and smooth vetch to find the influence of various low temperature treatments and alternating temperatures on the softening of hard seeds and on the germination of seed samples. The various treatments consisted of moist and dry storage of seed samples under the following conditions Room temperature; $5°$ C; $-10°$ C; $-10°$ C for 1 week followed by continuous storage at $5°$ C; alternations in weekly intervals between temperatures above and below freezing. Storage periods ranged from 1 to 10 months. At the close of a storage period for a sample, dead seeds and seed which had produced radicles more than 1 cm in length were discarded. The remainder of the sample was tested for germination.

No low temperature storage treatment was found which would cause seed samples of sweet clover and smooth vetch to give higher germination percentages than seed samples which had been stored dry at room temperature. Moist storage of the seed samples under the various low temperature and alternating temperature conditions was found to be harmful to germination. Permeable seeds produce radicles slowly in low temperature storage slightly above freezing. Permeable seeds which had absorbed enough water to be slightly swollen were injured or killed by freezing. Dry storage of seed samples under the same conditions was observed to have no significant influence on germination.

The various moist and dry storage treatments were observed to have no significant influence on the softening of hard seeds of sweet clover after storage periods ranging from 1 to 10 months. The various moist storage treatments were observed to be effective in the softening of hard seeds of smooth vetch. Samples of 200 hard seeds each were given the treatments. After 6 months storage only approxi-

mately 20% of the original hard seeds were still impermeable. In all cases hard seeds which had softened germinated normally when they were not frozen after taking up water. These results would indicate that probably the majority of hard seeds of smooth vetch would germinate and produce plants within the first 2 or 3 months after planting.

LITERATURE CITED

1. HARRINGTON, G. T. Agricultural value of impermeable seeds. Jour. Agr. Res. 6:761-796. 1916.
2. HARRINGTON, G. T. Use of alternating temperature in the germination of seeds. Jour. Agr. Res. 23:295-333. 1923.
3. HELGESON, EARL A. Impermeability in mature and immature sweet clover seeds as affected by conditions of storage. Trans. Wisconsin Acad. Sci. Arts and Letters 27:193-206. 1932.
4. JONES, JOHN PAUL. A physiological study of dormancy in vetch seed. Cornell Univ. Agr. Exp. Sta. Memoir:1-50. 1928.
5. LEGGATT, C. W. The agricultural value of hard seeds and sweet clover under Alberta conditions. Sci. Agr. 8:243-264. 1928.
6. LUTE, ANNA M. Impermeable seeds of alfalfa. Colorado Agr. Exp. Sta. Bul. 326:1-36. 1928.
7. MIDGLEY, A. R. Effect of alternate freezing and thawing on the impermeability of alfalfa and doder seeds. Jour. Amer. Soc. Agron. 18:1087-1098. 1926.
8. MORINAGA, TOSHITARO. Effect of alternating temperature upon the germination of seeds. Amer. Jour. Bot. 13:141-158. 1926.
9. SCHMIDT, DAVID. Work on hard seed problem to date. Seed World 19: No. 1, p. 9. 1926.
10. WHITCOMB, W. O. Hard seeds in legumes. Mont. Ag. Exp. Sta. Bul. 248:1-63. 1931.

PLOWING DATES AS THEY AFFECTED THE ABUNDANCE OF CORN ROOT APHIDS AT CLAYTON, ILLINOIS, 1929-1932[1]

J. H. BIGGER AND F. C. BAUER[2]

FOR many years the sole cultural practice recommended for the control of the corn root aphid, *Anuraphis maidi-radicis* Forbes, has been early plowing followed by repeated frequent discing of the soil to prevent re-establishment of the nests of the cornfield ant, *Lasius niger americanus* Emery, and growth of weeds to furnish food for the aphids prior to corn planting.

This recommendation probably originated with the extensive report on this insect by Dr. Forbes[3] in 1892 when he said, ". . . we may seek to handle the ground in such a manner that there will be no sufficient start of vegetation to keep the lice alive."

It was further developed and given a background of fact as reported by Flint[4] in 1919, and is recognized as an entirely satisfactory means of preventing damage by this insect. The authors wish in no way to displace this means of control when it can be carried out. It is desired only to furnish for the use of other workers in this line certain data obtained in pursuing a long-time project on observation of the effect of certain cultural practices on the root-infesting insects of corn.

HISTORY OF PROJECT

For four years, 1929-32, one part of this project was maintained in cooperation with the Department of Agronomy of the University of Illinois on the soils experiment field at Clayton in western Illinois on well-drained brown silt loam. A rotation of corn, oats, red clover, and wheat was practiced on the major series of this field. In this rotation, a grain system and livestock system of farming were compared. In the grain system sweet clover was grown in the wheat as a catch crop. This was returned to the soil the next spring as a green manure previous to corn planting. Corn crop residues were also returned to the soil. In the livestock system animal manure equal to the total weight of the crops produced in the previous rotation was spread on the ground and plowed under for corn. In both groups the first crop of red clover was removed for hay. The second crop was also removed for hay in the livestock system, but this crop was plowed under in the grain system previous to wheat seeding. (A common practice in Illinois is to gather the second crop of red clover for seed.)

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[1]Part of Project 3.6 of the Illinois Natural History Survey. Received for publication April 27, 1939.

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[3]FORBES, S. A. 18th Rpt. Ill. State Ent., 1891-1892. (Page 66.)

[4]FLINT, W. P. Ill. Nat. Hist. Sur. Circ. 4. 1919.

GRAIN SYSTEM	LIVESTOCK SYSTEM
Late plow	Late plow
Early plow	Early plow

FIG. 1.—Diagram of arrangement of soils experiment field at Clayton, Ill.

Plowing for corn was done in such a way that each of these areas was plowed at two different dates, the plowing being done at the same time in each, as indicated in the diagram in Fig. 1. Approximately 1 acre is included in each of the four resulting areas.

The early plowing is done as soon as sweet clover has made sufficient growth to be killed by turning under. The late plowing is done approximately two weeks later and about a week previous to corn planting. The early plowed land is not worked further until after the second plowing is done when the entire series is double disced and harrowed just previous to corn planting. The term "early plowing" is here used only to indicate the difference between the two groups. These dates of plowing (Table 1) would not ordinarily be considered early in the section of the state in which the field is located.

TABLE 1.—*Record of dates of plowing and planting at Clayton, Ill., 1929–32.*

Year	Early plowing	Late plowing	Planted	Date recorded
1929	Apr. 19	May 9	May 17	June 20–21
1930	Apr. 8	Apr. 23	May 6	June 2–3
1931	Apr. 15	May 1	May 13	June 8
1932	Apr. 13	Apr. 27	May 5	May 27

It is recognized that the early plowed area is not handled according to recommendations for corn root aphid control, but this handling is in general agreement with common practice followed by farmers in this area. The infestation later shown is not to be considered that which would result if previous control recommendations were followed.

METHOD OF GATHERING DATA

Corn is planted on these plats during the first part of May and cultivated in the usual manner. When the plants have reached a height of 6 to 8 inches, representative groups are dug in each plat. Duplicate 100-hill samples are taken in different sections of the series. The plants are dug with a spade and the entire root system present at that time is exposed. Visible presence of the insects themselves is the only basis for record of infestation. The practice of plowing twice on the field has been discontinued. Further records are not obtaina[illegible] the data are here offered following only four years' study.

RESULTS OBTAINED

From the start of taking records it was apparent that the practice of plowing in the first half of April and not working the ground until just prior to corn planting resulted in a heavier infestation than the practice of plowing a week prior to corn planting and thorough working of the soil in the meantime. These results were consistent for the four-year period when the records were obtainable as shown in Table 2.

TABLE 2.—*Infestation by corn root aphids under two different cultural practices.*

Cultural practice	Percentage of hills infested					
	1929	1930	1931	1932	Average	Composite average
			Early Plowing			
Livestock system	49.7	21.5	—*	30.0	33.6	26.5
Grain system	32.1	13.0	2.5	30.0	19.4	
			Late Plowing			
Livestock system	32.9	14.5	11.0	14.4	18.2	15.7
Grain system	23.9	11.0	1.5	16.3	13.2	

*Plats not included in 1931.

RECOMMENDATIONS

The authors hesitate to make any formal recommendation on the basis of the four years of work on only one series of plats, though duplicate records were obtained in each case. The fact that previous recommendations are entirely satisfactory when carefully followed is also considered. It is felt, however, that under certain conditions it can be recommended that plowing of the field be delayed until just prior to corn planting where corn root aphid control is the only factor to be considered.

This should not be used to replace previous recommendations where it is possible to follow them. It is recognized that this is not generally good farm practice and that early plowing should be generally considered superior. This practice is to be recommended only when and where corn root aphids are the only important problem and other means of control are not possible.

METHODS FOR DETERMINING THE PERCENTAGE OF SEEDS, STRIGS, STEMS, AND LEAVES IN COMMERCIAL HOPS[1]

C. G. MONROE AND D. D. HILL[2]

THE seeds, strigs (the rachis of the hop strobile), stems, and leaves in commercial hops add little to the brewing value. Brewers generally consider seedless hops to be superior to seeded hops as the seeds are believed to impart undesirable flavors and odors to the brewed beverages. All of these materials add useless weight to the hops.

Brewmasters and hop dealers have made it a practice to estimate roughly the amount of impurities in a given sample. If analyses are necessary, the stems and leaves can be picked from the sample and the percentage determined accurately. The stickiness of the lupulin which covers the base of the bracts of the hop cone and the enclosed seed makes accurate physical analysis of this factor difficult. Lupulin also interferes with accurate determination of strigs.

At the request of the Oregon hop industry, experiments were initiated by the Oregon Experiment Station to study the physical and chemical properties of commercial hops. In this study it was necessary to determine accurately the percentage of seeds in a given sample. A comprehensive review of the literature on the subject revealed only two methods that had been used to accomplish this objective.

Epstein and Hubbard[3] suggested a method in which the seeds were plucked from the cones by hand and the lupulin removed from the seeds by rubbing between the thumb and index finger. When the fingers became oily they were dipped in 50% alcohol and wiped clean. About 2 hours were required to determine the seed content. of a 10-gram sample, which, according to Epstein and Hubbard, was the smallest sample that would give representive results.

Rabak[4] offered a more practical method by which 20-gram samples were heated to 105° C for 6 hours to destroy the stickiness of the lupulin so that the hops could be threshed by pulverizing between the palms of the hands and the seeds then screened out. This method limits the output of a commercial laboratory to the capacity of its ovens.

MATERIALS AND METHODS

An experiment was set up for the purpose of developing a more practical method for arriving at seed percentages in hops. Three lots of hops appearing to

[1]Published as Technical Paper No. 312 with the approval of the Director of the Oregon Agricultural Experiment Station, Corvallis, Ore. Contribution of the Department of Farm Crops. Received for publication May 1, 1939.

[2]Graduate Assistant and Associate Agronomist, Farm Crops Department, Oregon State College, respectively.

[3]Epstein, S. S., and Hubbard, W. S., The American Brewer, June, 1936.

[4]RABAK, F. Relation of seeds, leaves, and stems to the quality of hops and malt beverages. Printed and distributed by Materials Improvement Committee, Master Brewers' Association of America, Clinton, Iowa.

vary in seed content were selected. Ten-gram samples from each of these lots were subjected to two types of treatments to destroy the lupulin. In one treatment the samples were exposed to various temperatures for 1 to 6 hours; in the other they were dipped in alcohol and then dried. From this experiment, the following methods were selected as the most promising: Heating at 105° C for 6 hours, heating at 115° C for 2 hours, and the alcohol-solvent method.

A second experiment was set up to determine the comparative accuracy of these three methods. From each of five different lots of commercial hops, three sets of five 20-gram samples were selected to be treated by each of the three methods. The samples were taken from hop bales and accurately weighed to 20 grams. All stems, leaves, and portions of leaves more than ¼ inch in diameter were picked out and weighed to 0.01 gram, and the percentage determined. In the first experiment it had been found that it was more practical to separate the stems and leaves before heating or dipping in alcohol, as the leaves were less likely to be broken and therefore more easily removed. The samples to be heated were placed in covered soil cans and heated in a thermostatically controlled electric oven in which the temperature would be controlled with an accuracy of ±2° C.

The individual samples for the alcohol-solvent method were placed on 2-foot squares of muslin or cheesecloth and immersed in a quart bowl of methyl alcohol for 1 minute. The excess alcohol was pressed by hand from the sample and retained for further use. Rubber-coated gloves were used to protect the operator's hands from the staining effect of the alcohol and lupulin.

The cloth containing the hops was next spread out to dry on a screen over a steam radiator. Breaking up the cones and stirring them occasionally speeded up the drying process. Twenty to 30 minutes were required for drying.

Identical methods of threshing were used for all treatments. The cones were pulverized between the palms of the hands, and the chaff separated from the seeds and strigs, or central stems of the cones, with a laboratory fanning mill. The seeds were readily separated by screening out the larger strigs, then placing the seeds and remaining strigs on an incline and manipulating in such a manner that the seeds rolled off while the irregularly shaped strigs do not. The seeds and strigs were weighed separately and their percentages by weight determined. The weight per 1,000 seeds was determined for each treatment.

EXPERIMENTAL RESULTS

Results of the preliminary trials are shown in Table 1. This experiment indicates that heating at higher temperatures for shorter periods of time is comparable to the 6-hour treatment at 105° C, and that the alcohol-solvent method compares favorably with the heat treatments. The variations in seed percentages, though small, indicated that the 10-gram samples were too small.

Individual percentages of seeds and strigs with averages for each sample and each treatment are shown in Table 2. The data obtained from all three methods show comparable results, although the percentage of error from the 2-hour heat treatment is slightly higher than from the other two methods.

For convenience, the averages from Table 2 are summarized in Table 3.

DISCUSSION

The percentage of probable error indicates the variations within each of the different methods, part of which is the result of variations

TABLE 1.—*Comparison of methods of seed determination in hops, preliminary trial.*

Treatment	Lot 45A		Lot 37		Lot 51	
	% seeds	Condition*	% seeds	Condition*	% seeds	Condition*
Heat, 105° C, 1 hr.	9.2	Slightly sticky	11.2	Slightly sticky	19.0	Sticky
Heat, 105° C, 2 hrs.	6.5	OK	11.8	OK	16.5	Slightly sticky
Heat, 105° C, 3 hrs.	7.6	OK	8 9	OK	16.1	Slightly sticky
Heat, 105° C, 4 hrs	7 3	OK	12 0	OK	16.5	Slightly sticky
Heat, 105° C, 5 hrs	7.4	OK	10 1	OK	17.0	OK
Heat, 105° C, 6 hrs	7.1	OK, cones brown	11.1	OK	17 7	OK
Alcohol solvent	8 3	OK	11 5	OK	17.2	OK
Alcohol solvent	6.9	OK	11.1	OK	17 9	OK
Alcohol solvent.	7.0	OK	9.9	OK	17 5	OK
Alcohol solvent	8 0	OK	11 5	OK	18.9	OK
Alcohol solvent	6 8	OK	10.8	OK	18.2	OK
Average	7.4		11 0		17 9	
P.E. ±†	0 254		0.287		0.203	
P.E %	3 43		2.61		1 13	

Trials at Higher Temperatures with Lot 45A

No.	115° C, 2 hrs.		120° C, 2 hrs.		120° C, 1 hr.	
	% seeds	Condition	% seeds	Condition	% seeds	Condition
1	8.2	OK	8.6	OK, tobacco brown	8.1	Slightly sticky
2	7.2	OK	8.0	OK, tobacco brown	7.3	OK
3 . . .	8.8	OK	8.0	OK, tobacco brown	9.2	Slightly sticky

*Condition refers to the condition of the sample for threshing.
†Probable error computed by Peter's formula

in sampling. The low percentage of error in all cases indicates that all of these methods are reasonably accurate.

Results of the heat trials indicate that the 2-hour method at 115° C is as accurate as the 6-hour method at 105° C. One advantage of the former is that it will enable a laboratory to analyze four times its oven capacity in an 8-hour day. Where oven space is the limiting factor, this is a decided advantage over the 6-hour method.

The alcohol-solvent method gave results comparable to those obtained from the heat treatments. The determination of strigs by

TABLE 2.—*Comparison of methods of seed determination in hops, final experiment.*

No.	Lot 27A		Lot 51A		Lot 44		Lot 49A		Lot 8A	
	% strigs	% seeds	% strigs	% seeds	% strigs	% seeds	% strigs	% seeds	% strigs	% seeds
					Alcohol-Solvent Method					
1	8.6	4.0	8.5	7.7	8.0	8.6	8.9	15.0	7.6	19.7
2	7.3	3.9	9.9	7.9	8.0	9.0	8.9	15.4	8.5	20.8
3	7.4	4.1	10.2	8.4	8.3	8.1	9.2	15.5	8.4	20.3
4	8.7	4.1	9.7	7.8	7.4	10.3	9.0	15.5	8.9	20.0
5	8.3	3.8	10.2	8.1	7.9	10.1	9.6	16.3	7.7	21.3
Ave.	8.1	4.0	9.7	8.0	7.9	9.2	9.1	15.5	8.2	20.4
P. E. ±	0.237	0.042	0.203	0.093	0.093	0.330	0.093	0.118	0.194	0.211
P. E. %	2.93	1.05	2.09	1.16	1.18	3.59	1.02	0.76	2.37	1.03
Weight of 1,000 seeds, grams		3.92		4.23		3.64		4.10		3.27
					Heat at 115° C for 2 Hours					
1	7.8	4.1	9.1	8.9	7.5	8.0	7.5	15.0	9.0	22.0
2	8.5	3.8	8.0	8.0	7.2	9.0	5.1	13.2	8.2	19.8
3	8.1	4.6	7.8	9.5	7.4	8.7	8.2	15.5	7.1	20.6
4	8.1	3.8	6.5	8.2	5.0	10.1	6.5	15.8	8.8	21.4
5	8.4	4.2	7.5	7.5	6.0	8.4	6.7	16.1	7.8	19.0
Ave.	8.2	4.1	7.8	8.4	6.6	8.8	6.8	15.1	8.2	20.6
P. E. ±	0.093	0.101	0.262	0.262	0.380	0.237	0.355	0.346	0.245	0.389
P. E. %	1.13	2.46	3.36	3.12	5.76	2.69	5.22	2.29	2.99	1.89
Weight of 1,000 seeds, grams		3.70		4.44		3.70		4.30		3.14
					Heat at 105° C for 6 Hours					
1	7.1	4.0	9.2	8.1	5.0	8.3	5.6	13.3	7.5	20.6
2	6.7	3.8	7.2	8.0	4.8	8.4	7.0	13.2	7.4	19.7
3	8.2	4.4	8.6	8.2	5.3	9.5	7.4	13.6	7.1	19.4
4	8.3	4.8	8.0	7.4	6.6	9.4	6.1	13.7	7.4	19.0
5	8.0	3.9	8.4	8.1	7.5	8.5	7.2	14.2	7.0	19.9
Ave.	7.7	4.2	8.3	8.0	5.8	8.8	6.7	13.6	7.3	19.7
P. E. ±	0.253	0.144	0.228	0.084	0.406	0.211	0.270	0.118	0.076	0.177
P. E. %	3.28	3.43	2.75	1.05	7.00	2.40	4.03	0.87	1.04	0.90
Weight of 1,000 seeds, grams		3.93		4.36		3.74		4.08		3.36

TABLE 3.—*Comparison of the averages of the three methods, summary of Table 2.*

	Alcohol solvent			Heat, 115° C, 2 hrs.			Heat, 105° C, 6 hrs.		
	% by weight	% P.E.	Weight of 1,000 seeds, grams	% by weight	% P.E.	Weight of 1,000 seeds, grams	% by weight	% P.E.	Weight of 1,000 seeds, grams
Seeds	11.4	1.52	3.85	11.4	2.49	3.86	10.9	1.73	3.89
Strigs	8.6	1.92	—	7.5	3.69	——	7.2	3.62	—

this method appeared to be slightly more accurate, as indicated by a lower probable error. An important advantage of the method is that no oven is required and that the work can be done wherever facilities are available for drying. In the opinion of the senior author, who conducted most of the actual trials, samples treated with alcohol threshed more easily and were more satisfactory to handle. Heating appeared to cause parts of the bracts to adhere to the seeds, thus interfering in threshing.

The alcohol-solvent method was adopted by the Oregon Experiment Station. It was used on approximately 1,000 samples from more than 300 different lots of commercial hops and gave satisfactory results. Results were entirely satisfactory. Experience shows that one man can determine the percentages of stems, leaves, seeds, and strigs of 25 20-gram samples in one 8-hour day, using only 3 pints of methyl alcohol.

SUMMARY AND CONCLUSIONS

To determine accurately the percentage of seeds in commercial hops, the lupulin must be removed. Lupulin is the sticky, yellow material which adheres to the seeds and the bases of the bracts making accurate separation difficult.

The use of methyl alcohol used as a solvent appears to be the most satisfactory method of those tried. The short time and the small amount of equipment and materials required, the simplicity of the method, and its accuracy are definite advantages. This method is definitely more accurate for determining percentages of strigs than the heat methods, which tend to cause the strigs to become so brittle that they break and are lost in threshing.

Heating 2 hours at 115° C appears to be as satisfactory as heating 6 hours at 105° C.

Twenty-gram samples are easy to handle, and according to the probable errors obtained, they are sufficiently accurate to be dependable.

THE USE OF CROP RESIDUES FOR SOIL AND MOISTURE CONSERVATION[1]

F. L. Duley and J. C. Russel[2]

METHODS of crop production in the Great Plains have been greatly improved during the last 40 years. There remains, however, much to be done from the standpoint of reducing the number of crop failures. The hazards encountered in Great Plains agriculture are due not so much to the fact that the total rainfall is low as to its uneven seasonal distribution, high summer temperatures, and frequent extended periods of drought. The fact that most of the precipitation comes during the warm season makes it difficult to get deep penetration of water into the soil because of excessive evaporation losses The total loss of water by evaporation in the Great Plains may equal or exceed the amount used by the crop and may be two to four times as much as the water lost by runoff.

Any method for increasing the efficiency of Great Plains rainfall should include the possibilities for improving moisture conditions by reducing the rate and amount of evaporation of water from the soil surface Although the losses due to runoff may be the more easily controlled, if some practical method could be devised that would reduce simultaneously the moisture losses from runoff and from evaporation, it would be a definite step toward maximum efficiency of rainfall utilization.

In the experiments herein reported an attempt is being made to utilize crop residues directly to increase the efficiency of rainfall for plant production in regions of low precipitation. Under the present system of harvesting most of the small grain and some sorghums with combines, much more crop residue than formerly is left on the land. Furthermore, these residues are spread quite evenly over the surface of the fields. It has long been known that debris of any sort on top of the ground will increase the intake of water and also reduce evaporation. Recent results obtained by Duley and Kelly (2)[3] through the artificial application of water have shown that the stubble and straw residue left by the combine is very effective in increasing the amount of infiltration that takes place during rains. Compared with cultivated bare soil, even a light covering of crop residue will greatly increase the amount of water entering the soil and will also reduce the evaporation loss of soil moisture. Erosion by either wind or water may be reduced to a minimum or practically eliminated where there is an appreciable amount of crop residue on top of the soil.

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[3]Figures in parenthesis refer to "Literature Cited", p. 709.

UNCROPPED PLATS

In order to test the effect of crop residues on the amount of moisture that could be stored in uncropped land during the season, plats were started in the spring of 1938 with the treatments shown in Table 1. These plats were located at the Agronomy Farm, Lincoln, Nebraska, on a heavy subsoil Marshall silt loam with a slope of about 5%.

TABLE 1.—*The effect of straw and different tillage treatments on the storage of water in the soil.*

Plat No.	Treatment*	Rainfall conserved		Depth of water penetration, feet
		Surface inches	%	
1	Straw, 2 tons disked in	6.92	38.7	5
2	Land disked, no straw	3.49	19.5	4
3	Straw, 2 tons on the surface	9.72	54.3	6*
4	Straw, 2 tons plowed in	6.12	34.2	5
5	Land plowed, no straw	3.71	20 7	4
6	Decayed straw, 2 tons plowed in	3.12	17.4	4
7	Basin listed	4.95	27.7	5

*A second application of straw was made to these plats on August 9, 1938

Samples were taken to a depth of 6 feet on these plats April 23, May 24, July 14, August 9, and September 8. The samples were from four separate locations in each plat. They were taken in foot sections except the surface layer which was divided into two 6-inch sections. Weeds were kept down on the plats by hoeing except where the straw was on the surface. Here the cultivation was done by means of a broad duckfoot cultivator with sweeps 22 inches across which has been devised to cultivate the land and leave the crop residue on the surface. (See Figs. 1 and 2.)

The results from this phase of the work have been summarized in Table 1 by showing the total accumulation of moisture under different methods of fallow during the season between April 23 and September 8, 1938. During this time 17.9 inches of rain fell and the amount of moisture saved under each treatment is shown as percentage of total rainfall, in surface inches, and in depth of penetration of the water into the soil.

It will be noted from Table 1 that where straw was applied on the surface 54.3%, or 9.72 inches, of water was saved during the season. When this is compared with ordinary methods of clean fallow reported on plat 5, it will be seen that the moisture saved is more than two and one-half times that on the plowed land. The moisture saved on bare fallow is in line with results of other work done on some of the dry land experiment stations (1, 4). The moisture saved when the straw was disked in or plowed in was much more than on land plowed without straw, because a considerable amount of straw was left sticking out which protected the surface and reduced runoff. The moisture saved where the straw was plowed under was less than on land where the straw was on the surface or simply disked into the top soil.

FIG 1 —Broad sweep shovel for cultivating soil with crop residues on the surface This tool will kill weeds cultivate the soil and leave the debris on top of the ground for protection against runoff erosion and evaporation This type of shovel with a higher and more curved shank has been fitted to a tractor drawn heavy type duckfoot cultivator and used successfully on combine stubble land

FIG 2 —Straw-covered plat which has been cultivated with broad duckfoot cultivator Note that the straw has been left evenly distributed over the surface

It should be further noted that on plat 6, where the decayed organic matter was plowed under, there was no advantage so far as moisture conservation is concerned over plowing with no straw

The results with basin listing are of particular interest because on this land there was no runoff, yet the amount of water conserved

during the season was only half the amount stored under straw. This emphasizes the fact that preventing runoff is not the full solution for the moisture problem in the Great Plains. On this plat the losses due to evaporation from the convoluted bare surface tended to offset the gains due to the prevention of runoff. The basin listing did, of course, prevent erosion, but this was also true where the straw treatments were used. The results indicate that in both the plats where straw was left on or near the surface, there was a decided saving of moisture over that on the basin listed land.

CONSERVING MOISTURE IN PREPARATION OF A WHEAT SEEDBED

In order to obtain further information on the effect of crop residues in moisture conservation and also to determine their effect on crop yields, experiments are being started in which use is being made of the residue from different crops in conserving moisture in the soil. A rotation of corn, oats, and wheat is being used in which the straw from the small grain crops and the corn stover will be returned and maintained on the surface for a time to aid in soil and moisture conservation. Following the oats crop in 1938 the straw was removed and in its place a weighed amount of wheat straw was returned amounting to 2 tons per acre. This was done on August 1, at which time soil moisture samples were taken and the treatments shown in Table 2 were applied to triplicate plats. During the period August 1 to September 21, the rainfall was 8.34 inches. In Table 2 is also given the amount of rainfall saved in surface inches and in percentage of the total rainfall, and also the depth of penetration of moisture into the soil.

TABLE 2.—*The effect of straw and different tillage treatments on the storage of water in stubble land being prepared for winter wheat, Aug. 1 to Sept. 21, 1938.*

Plat No.	Treatment	Rainfall conserved		Average depth of water penetration, feet
		Surface inches	%	
1	Straw, 2 tons on surface, land worked with one-way disk	4.16	49.9	2.7
2	Straw, 2 tons on surface, worked with sub-surface duck-foot cultivator	4.05	48.6	2.6
3	Straw, 2 tons, basin listed	3.80	45.6	2.8
4	Straw, 2 tons, plowed in	3.04	36.4	2.1
5	No straw, land plowed	1.87	22.4	1.6

It will be noted that where the straw was left on top or disked into the surface, almost half of the rainfall was held in the soil. The basin listing in this case stored 45.6% of the rainfall, which was more nearly equal to the amount saved by the straw treatments than was the case in the uncropped series reported in Table 1. Where the straw was plowed in, even though a certain amount of straw was not completely covered, the saving of moisture dropped to 36.4% and where

the straw was removed and the land plowed the amount of moisture saved was only 22.4%. On the land where the straw was on or near the surface water penetrated well into the third foot. This was also the case where the land was basin listed, but here the moisture was deeper under the furrows than under the ridges. Where the land was plowed, moisture was down only slightly below the 2-foot level and on the land plowed after the residue had been removed, water had reached only 1.6 feet. Work done on the dry-land experiment stations in the Great Plains has shown that the depth of penetration is of much importance for the following wheat crop (3). A distinct advantage has been gained both in total water saved and in depth of penetration where the crop residue has been left on the surface of the ground.

CROP RESIDUES ON CORN LAND

The idea of protecting the surface of the soil from runoff and evaporation and thus obtain a maximum conservation of water throughout a whole cropping system was extended to a series of corn experiments conducted during 1938. Wheat straw at rates of 2, 4, and 8 tons per acre was applied on the surface of the soil having a slope of about 5% that was to be planted to corn. Some of these rates are very high, and they were used mainly for the purpose of determining the maximum effects on moisture conservation and also for the purpose of determining whether such applications might have any detrimental effects on the growth of corn resulting from a reduction of the available nitrogen or other plant food material. In these tests the furrows for corn were made by means of disk furrow openers and the straw was applied by hand between the rows. When the corn was cultivated, the small ridge of soil thrown out in making the furrow was pulled back around the corn in order to free the row of weeds. The land between the rows was relatively clean and required very little cultivation. The cultivation that was finally given was by means of a heavy hoe drawn underneath the straw cutting only about an inch of soil. These straw-treated plats were compared with plowing and with basin listing. All of the plats were on the contour on an approximate 5% slope.

Results obtained in this first year's test should be considered only preliminary. In the first place, the 1938 season was unfavorable for corn in this part of Nebraska and grasshoppers did considerable damage. Methods of cultivation adapted to corn land with a considerable amount of debris on the surface have not yet been perfected. The total yield of air-dry fodder was low, but there were some differences which are of interest in connection with this whole idea of soil and moisture conservation by the more effective use of crop residues. Table 3 shows the treatments, which were carried out in quadruplicate, the yields of fodder, and the surface inches of water stored by these different treatments to a depth of 6 feet in excess of that stored by the check plats.

No measurements of runoff or erosion were made on these plats. It was observed, however, after different rains during the season that a considerable amount of runoff and erosion had taken place on the

TABLE 3.—*The effect of straw treatments on yields of corn fodder and storage of soil moisture, May 18 to Sept. 27, 1938.*

Plat No.	Treatment	Yields of air-dry fodder per acre, lbs.	Relative yields, %	Moisture storage due to treatments in excess of check, surface inches
1	Land plowed and planted with furrow openers	3,890	100	—
2	Basin listed	4,270	109	0.23
3	Straw, 2 tons per acre between rows	4,870	125	1.42
4	Straw, 4 tons per acre between rows	5,080	130	2.87
5	Straw, 8 tons per acre between rows	5,350	137	3.20

check plats. Soil had been carried across these plats and deposited in the first row of the straw-covered plat below. There was no evidence of either runoff or erosion on any of the mulched plats.

DISCUSSION OF RESULTS

While the results reported in this paper must necessarily be considered as preliminary in nature and are presented only as a progress report of this work, there are certain rather fundamental considerations regarding moisture conservation that seem to be indicated.

In the first place, leaving crop residues on the surface of the ground appears to be a very effective and practical method of conserving soil and soil moisture in the Great Plains. Used in this way they may be expected to have the following beneficial effects: (a) Greatly increase infiltration and thereby reduce the amount of runoff; (b) reduce evaporation from the surface soil; (c) reduce the amount of water erosion; and (d) reduce the amount of wind erosion.

It is also recognized that this organic debris left on the surface of the soil for an extended period may have many other physical, chemical, and biological effects, some of which may be favorable and some unfavorable to crop production, but no attempt will be made here to discuss any of these factors. The decayed part of the residue as well as a certain amount of undecomposed material would, of course, be gradually worked into the soil by whatever cultivation practice that may be used. This decayed organic matter incorporated with the soil may aid in the maintenance of fertility, but in these tests it had little effect on the storage of soil moisture.

These tests, along with much practical experience by farmers, would seem to emphasize the importance of continuous protection of land in the Great Plains, either by a growing crop or by the use of crop residues on the surface until another crop can be started.

The results reported in this paper indicate that for storing and conserving moisture in the soil, protecting the land with plant residues when available in sufficient quantity may be a much more efficient method than is the use of clean or "black" fallow now so generally

used throughout the regions of low rainfall. It must be remembered that a cultivated bare soil is the surface condition in which land is most likely to lose excessive amounts of water by runoff, permit the greatest loss by evaporation, and submit the soil to the greatest possible hazard from erosion by either wind or water.

When all these things are considered, it would seem that the proper utilization of crop residues on the surface of the soil may offer a simple and practical method for reducing runoff and erosion. By increasing infiltration and reducing evaporation losses a more efficient use may be made of the rainfall, which appears to be absolutely necessary for the maintenance of a stable and permanent agriculture in the Great Plains.

LITERATURE CITED

1. Burr, W. W. The storage and use of soil moisture. Nebr. Agr. Exp. Sta. Res. Bul. 5. 1914.
2. Duley, F. L., and Kelly, L. L. Effect of soil type, slope, and surface conditions on intake of water. Nebr. Agr. Exp. Sta. Res. Bul. 112. 1939.
3. Hallsted, A. L., and Mathews, O. R. Soil moisture and winter wheat with suggestions for abandonment. Kan. Agr. Exp. Sta. Bul. 273. 1936.
4. Thysell, J. C. Conservation and use of soil moisture at Mandan, N. D. U. S. D. A. Tech. Bul. 617. 1938.

THE BREEDING OF IMPROVED SELFED LINES OF CORN[1]

H. K. HAYES AND I. J. JOHNSON[2]

COMMERCIAL and experiment station plant breeders are of the opinion that there will continue to be a rapid increase in the use of hybrid corn until the greater part of the field corn acreage in the United States is planted to hybrid varieties. The reasons for the rapid expansion of hybrid corn are rather well known. The primary cause is the greater efficiency of adapted hybrids in yield per acre, ability to withstand lodging, uniformity of maturity, disease resistance, and other important characters.

The explanation of hybrid vigor was placed on a Mendelian basis by Jones (7)[3] and the results of experiments by Richey and others (8, 9) have given some evidence that lends added support to this explanation. If the Mendelian explanation proves the correct one, it furnishes a genetical basis for the belief that improved inbred lines can be developed by the same plant breeding methods that have been so successfully applied to self-pollinated crop plants.

Most of the inbreds already used in commercial hybrids have been obtained by self pollination and selection from commercial varieties All inbred lines of field corn now available are much less vigorous than the normal varieties from which they were selected. An inbred line may be far superior, however, to the commercial variety from which it was selected in some one character, such as ability to withstand lodging or disease resistance. The major difference in the breeding of improved selfed lines of corn from crosses between available inbreds and subsequent selection in self-pollinated lines and the breeding of improved varieties of self-pollinated plants is the necessity of controlling pollination in corn.

After a wide collection of selfed lines has been selected from normally pollinated adapted varieties and from other breeders, three rather specific methods of breeding are available in the development of improved inbreds. These are the pedigree method, backcrossing, and convergent improvement. Backcrossing and convergent improvement are being used extensively by many corn breeders. Convergent improvement is a method of double backcrossing and, as originally developed by Richey (8), was suggested as a method for testing the Mendelian explanation of hybrid vigor. In its application to plant breeding it was proposed as a means of improving each of two inbred lines without materially changing their combining ability in an F_1 cross.

Backcrossing appears a logical method when one desires to add one or two characters which a variety or inbred line lacks and to retain the many desirable characters of the variety or inbred line used as the recurrent parent. This can be accomplished most easily when the character to be added is simply inherited. Most inbred lines are great-

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[3]Figures in parenthesis refer to "Literature Cited", p. 723.

ly lacking in growth vigor when compared with normal varieties. It seems probable that multiple factors are responsible for growth vigor. Inbred lines, therefore, may differ from each other and from normal varieties by many inherited factors. Under these conditions the pedigree method of breeding used so extensively in breeding improved varieties of self-pollinated plants seems equally satisfactory as a method of breeding improved selfed lines of corn. The purpose of this paper is to report some of the results obtained from the pedigree method as used to breed improved selfed lines adapted to Minnesota conditions.

MATERIAL AND METHODS

Commercial varieties of corn grown in Minnesota are, in general, lacking in ability to withstand lodging and for this reason selection for lodging resistance has been made since 1915 when selection in self-fertilized lines was first undertaken. Several inbred lines were obtained from Minnesota commercial varieties during 1915 to 1928 that were superior to the average in non-lodging ability. In addition, several inbreds from other breeders were selected that were outstanding in ability to withstand lodging. Crosses were made in such a manner that in nearly all cases one of the parents in each cross excelled in ability to withstand lodging and in resistance to smut. Pedigree selection was practiced from the F_2 to F_6 generation for vigor of growth, earliness of maturity, ability to withstand lodging, smut resistance, and other characters.

A considerable number of the inbred lines used as parents in these crosses were studied by Hall (4), who summarized the lodging indices of the inbreds using data furnished him from the breeding plats during 1927 to 1930, and who took further data on lodging from 1931 to 1933, inclusive. In Table 1 the parental lines are placed in various groups on the basis of strength of stalk and smut reaction. The smut reaction is on the basis of average smut infection taken in recent years, 1935 to 1937, inclusive.

TABLE 1.—*Lodging and smut reaction of inbreds used as parents of crosses.*

Inbred line	Former culture	Variety source	Smut reaction, %	Lodging index*
A9	C49	Minn. No. 13	9	I
A2	C43	Minn. No. 13	40	I–
A12	C11–28	Minn. No. 13	18	S
A48	64	N. W. Dent	28	S
A39	15–28	Rustler	33	I
A26	9–29	Osterland's Dent	6	S
A25	8–29	Purdue Dent	24	S

*S = strong stalk; I = intermediate.

Crosses made in 1929 were as follows: A48 with A9, A12, and A39; A9 with A39 and A26; A12 with A39; and A39 with A25 and A26. In addition, a few cultures were grown from crosses made at the Waseca branch station including a cross of A48 × H and A48 × 4–29, crosses between an inbred culture of N.W. Dent with an inbred from Reid's Yellow Dent and Silver King, respectively. It will be noted that one of the parental inbreds excelled in smut resistance in most crosses made. Selection in self-pollinated lines was practiced from F_3 to F_6, inclusive, the number of ear cultures grown each year, showing the extent of the studies, were

as follows: F_3, 729; F_4, 538; F_5, 198. In addition to these crosses 75 to 100 ear progenies were grown of crosses between A2 with inbred cultures 46 and 47 from Minn. No. 13, these crosses being made originally to select lines that were resistant to *Gibberella saubinetii* in the seedling stage, culture A2 being outstanding in this respect. Besides selecting inbreds from crosses, further selection was made in inbred lines of Minn. No. 13, Golden Gate, and a late strain of Minn. No. 13 known as Kalmoe.

The 7 parental inbred cultures given in Table 1, 13 new inbreds selected in Minnesota from commercial varieties, 4 inbreds introduced from Wisconsin, 16 inbreds from crosses of A2 with inbreds 46 and 47 selected from Minn. No. 13, and 70 inbreds selected by the pedigree method from crosses between inbreds that excelled in ability to withstand lodging were used in studies of the relation between the characters of inbreds and their combining ability.

These inbreds were grown at University Farm during 1935 to 1937. The 110 individual cultures were grown in short row plats of approximately 25 plants each, in single plant hills spaced 1 foot apart, two replications in randomized blocks being used for each inbred line. Data were taken on each plat separately and results for the three years were averaged to give the average expression for 14 characters of each of the inbred lines Separate analyses of variance were made for each of these characters and in each case significant variability between inbred lines was found.

The characters studied need not be described in great detail. They included date silked, plant height, ear height, leaf area, pulling resistance, root clump volume, stalk diameter, total brace roots, tassel index, pollen yield, percentage of smutted plants, ear shank length, yield index, and length of ear. Many of these characters required only a simple measurement and need not be described. Pulling resistance refers to number of pounds required to pull a plant from the ground. Root clump volume is the number of cubic inches obtained by multiplying $(\text{width})^2 \times \pi/4 \times$ depth of clump. Total brace roots is the actual number of brace and secondary roots established in the soil. Tassel index was placed on a reading of from 1 to 4, measuring the number of tassel branches and general vigor of tassel development with 4 representing the most vigorous class. Pollen yield was measured in cc after collecting pollen by bagging the tassel. Yield index was measured in percentage of the average of all cultures and expresses the relative ability of inbred lines to produce seed when self pollinated, cross pollinated, or under normal field pollination. Certain of the characters of inbreds obtained from the various crosses were summarized in frequency tables to show the extent to which it was possible to produce improved inbred lines by the methods employed.

Each of the 110 inbreds was crossed with Minn. No. 13, using the inbred as the female and the inbred-variety crosses were compared in yield trials made during 1936 and 1937, tests in 1936 being made in Meeker County only and in 1937 at the Morris branch station and in Meeker County. Each trial was made in randomized blocks using approximately 20 inbred-variety crosses per block, and including also Minn. No. 13, Minhybrid 401, and 402, three replications being made at each locality. In all cases results for each inbred variety cross are based upon the average of trials in at least two localities. When trials were available for only two localities the results were corrected on the basis of performance of check varieties. Yielding ability and moisture percentage at husking of the inbred-variety crosses were expressed as percentages of the average for the checks. Plant height in inches, ear shank length, percentage smut infection, ear length, number of rows per ear, good ears per plant, and shelling percentage were also recorded.

Simple product moment correlation coefficients were computed to express the relationship between certain characters of inbred lines and their expression in inbred-variety crosses.

Ten of the 14 characters of the inbreds that by means of correlation coefficients showed a significant association between the characters as expressed in the inbreds and yielding ability in inbred-variety crosses were correlated with each other. A multiple correlation coefficient was computed to show to what extent the variability in yield of the inbred-variety crosses was dependent upon measurable character differences of the inbred lines.

Inbred lines, obtained by the pedigree method of breeding from crosses between inbred lines as the original source, were selected that had better than average combining ability in the inbred-variety crosses. The origin of inbreds used in these crosses is as follows:

Original Cross	Inbred Cultures Selected
A48×H	A94, A96
A48×A9	A90
A9 ×A39	A99
A9 ×A26	A102, A111, A116, A122, A124
A12×A39	A131
A39×A26	A136, A143, A145, A146
A2 ×46	A148
A2 ×47	A158, A163

Single crosses between inbreds were made in such a manner that the primary difference between groups related to the origin of the inbreds. Group I consisted of crosses between inbreds with no parents in common, illustrated by A94×A99; group II had one parent in common, as illustrated by A90×A111, with the inbred parent A9 in common; and group III had both parents in common, as illustrated by the cross A102×A111.

Yield tests of the single crosses were made at University Farm, St. Paul, the Morris branch station, Meeker County, and Breckenridge. Single row plats of 12 hills each were planted for each cross and the check varieties. Randomized blocks were used, with three replications at each locality. Four check varieties, consisting of the Morris and University Farm strains of Minn. No. 13 and Minhybrids 401 and 402, were included in each block. Perfect stand hills were harvested surrounded by corn and the final yields and moisture content were placed on a percentage basis of the average of the four check varieties.

EXPERIMENTAL RESULTS

BREEDING IMPROVED INBREDS

Pulling resistance was found by Hall (4) and others to be correlated with ability to withstand lodging, and accordingly pulling resistance gives some indication of the desirability of the inbreds selected from crosses. The inbred lines are classified in Table 2 for pulling resistance.

It will be noted that the first five parental inbred lines in Table 2 originate from Minnesota varieties and are not particularly outstanding in pulling resistance. Inbred lines introduced from Purdue and Wisconsin, A25 and A26, are much superior to the Minnesota inbreds in pulling resistance. Many of the inbreds selected from

TABLE 2.—*Pulling resistance of inbred lines in relation to origin (average 1935-37), University Farm.*

Origin of lines	No. of lines in classes for resistance to pulling in lbs.						
	100	150	200	250	300	350	Total
A9	—	1	—	—	—	—	1
A2	—	1	—	—	—	—	1
A12	—	1	—	—	—	—	1
A48	1	—	—	—	—	—	1
A39	—	1	—	—	—	—	1
A26	—	—	—	1	—	—	1
A25	—	—	—	—	—	1	1
Total	1	4	—	1	—	1	7
Minn. No. 13	1	2	1	—	—	—	4
Golden Gate	1	2	2	—	—	—	5
Kalmoe	—	3	1	—	—	—	4
Wisconsin	—	1	—	2	1	—	4
A2×46	3	4	1	—	—	—	8
A2×47	3	4	1	—	—	—	8
A48×A9	1	3	3	—	—	—	7
A9×A39	—	—	1	—	1	—	2
A9×A26	2	3	17	1	—	—	23
A12×A39	—	4	3	—	—	—	7
A39×A26	1	1	13	2	2	—	19
A39×A25	—	1	6	—	—	—	7
A48×H	1	1	3	—	—	—	5
Total	13	29	52	5	4	—	103

crosses were intermediate in pulling resistance and they are superior on the average to those obtained from selfing and selection from Minnesota adapted commercial varieties, including Minn. No. 13, Golden Gate, and Kalmoe's No. 13. Root clump volume was studied in a similar manner. Thirty-five of the inbred lines obtained by the pedigree method of breeding from crosses were outside of the range of inbreds selected from Minnesota varieties and 14 of these were the equal in root volume of A25 or A26.

Percentage of smut of the inbred lines is given in Table 3. Selection for smut resistance was made during the segregating generations. Selfed ears from smut-free plants were used in propagating the cultures and selection was made also for cultures that were least severely infected with smut.

Seventy-one of 103 new inbred lines recorded in Table 3 were placed in the two lower classes for smut infection, while only 3 of the 7 original inbred lines used as parents were placed in these classes. From a considerable number of years experience it seems fair to conclude, that under the conditions of the experiment, a large proportion of the new inbreds is superior to normal Minnesota No. 13 and Rustler in resistance to smut.

TABLE 3.—*Smut percentage of inbred lines in relation to their origin (average 1935-37), University Farm.*

Origin of lines	No. of lines in smut percentage classes						
	5	14	23	32	41	50	Total
A9	1	—	—	—	—	—	1
A2	—	—	—	—	1	—	1
A12	—	1	—	—	—	—	1
A48	—	—	—	1	—	—	1
A39	—	—	—	1	—	—	1
A26	1	—	—	—	—	—	1
A25	—	—	1	—	—	—	1
Total	2	1	1	2	1	—	7
Minn. No. 13	—	—	—	2	2	—	4
Golden Gate	—	3	2	—	—	—	5
Kalmoe	1	2	—	—	1	—	4
Wisconsin	4	—	—	—	—	—	4
A2×46	6	1	1	—	—	—	8
A2×47	2	3	1	2	—	—	8
A48×A9	2	4	1	—	—	—	7
A9×A39	—	1	—	1	—	—	2
A9×A26	9	9	2	3	—	—	23
A12×A39	—	2	3	2	—	—	7
A39×A26	7	8	1	2	1	—	19
A39×A25	1	2	2	1	—	1	7
A48×H	—	4	—	—	1	—	5
Total	32	39	13	13	5	1	110

COMBINING ABILITY OF INBREDS

The combining ability of inbreds was determined by crossing each with Minnesota No. 13, using the method that has been accepted rather generally (2, 3, 5, 6), as a means of discarding lines of low combining ability. In most cases data are available from trials in Meeker County during 1936 and 1937 and at the Morris branch station in 1937. For two of the parental inbreds, A12 and A48, data were obtained only at Meeker County in 1936. Unfortunately, inbreds 46 and 47 were not tested in these top crosses, hence their combining ability can not be compared with that of the 16 inbreds descending from crosses involving these two lines. The results are shown in Table 4.

For the purpose of comparison the six frequency classes for combining ability can be divided into two groups, three lower classes including the parental inbreds selected from Minnesota No. 13 and Northwestern Dent and three upper classes including A39 selected from Rustler, A26 from Osterland's Dent, and A25 from Purdue Early. Inbreds selected from the cross of A48×A9, both low combining parents, were somewhat superior to the parents, on an average, in combining ability. Crosses of A9×A26 and A12×A39 were made between inbreds, one parent in each cross being of low combining

TABLE 4.—*Yielding ability in percentage of the checks of inbred-variety crosses in relation to the origin of the inbred lines.*

Variety source	Origin of lines	Yield classes in percentage						
		72	83	94	105	116	127	Total
Minn No 13	A9(49)	—	1	—	—	—	—	1
Minn No 13	A2(43)	—	—	1	—	—	—	1
Minn No 13	A12*(11 28)		—	1	—	—	-	1
N W Dent	A48*(64)	—	1	—	—	—	—	1
Rustler	A39(15 28)	-	—	—	—	—	1	1
Osterland's Dent	A26(9 29)	—	—	—	1	-	—	1
Purdue Early	A25(8–29)	—	—	—	—	—	1	1
Total			2	2	1		2	7
Minn No 13	Long Time Selfed	-	1	2	1	—	-	4
Golden Gate	Long Time Selfed	—	1	3	1	--	—	5
Kalmoe	Long Time Selfed	—	1	2	1	—	—	4
Wis lines	Long Time Selfed	-	—	1	2	1	—	4
Minn No 13	A2×46	—	2	3	3	—	-	8
Minn No 13	A2×47	-	—	2	4	1	1	8
Crosses between inbreds	A48×A49	—	1	4	2	—	--	7
Crosses between inbreds	A9×A39	—	—	—	2	—	—	2
Crosses between inbreds	A9×A26	1	—	5	12	5	-	23
Crosses between inbreds	A12×A39	—	—	1	5	—	1	7
Crosses between inbreds	A39×A26	—		-	5	14	—	19
Crosses between inbreds	A39×A25	—	—	—	3	3	1	7
Crosses between inbreds	A48×H	—	-		2	3	—	5
Total		1	6	23	43	27	3	110

*Inbred variety cross yield 1936 only

ability while the other parent was in one of the three upper classes in combining ability. A12 proved superior to A9 in combining ability while A39 was superior to A26 There seems to be some indication that inbreds of high combining ability can be selected relatively frequently from crosses of this nature. Twenty-six inbred lines were selected from crosses between A39, of extremely high combining ability, with A26 placed in class 105 for combining ability and from A39 with A25 where both parents were superior in combining ability. All 26 inbreds selected from these crosses were in the upper three classes for combining ability. There is considerable evidence that leads to the conclusion that the combining ability of inbreds selected by the pedigree method is associated with that of the inbred parents.

RELATIONSHIP BETWEEN CHARACTERS OF INBREDS AND OF INBRED-VARIETY CROSSES

The characters of the inbreds were determined from data collected from small plats grown at University Farm with two replications each year during 1935 to 1937. Data on inbred-variety crosses were obtained at three localities, although in several crosses the yield trials

were conducted in two localities only. Correlations between characters of the 110 inbreds and their inbred variety crosses are given in Table 5.

TABLE 5.—*Correlations between characters of 110 inbred lines and similar characters in inbred-variety crosses*

Inbred character	Inbred-variety cross character	r
Date silked	Moisture percentage at husking	0 5746
Plant height	Plant height	0 3677*
Smut percentage	Smut percentage	0 4638
Ear length	Ear length	0.4661
Shank length	Shank length	0 5431

*All correlations exceed the 1% point

Correlation coefficients were computed for average date of silking of the inbreds and moisture content at husking of the inbred-variety crosses, while the extent of correlation between plant height, smut percentage, ear length and shank length was determined for the same characters in the inbred and in the inbred variety crosses. The correlations in Table 5 are all positive and exceed the 1% point in level of significance, the extremes being 0 3677 for plant height and 0 5746 for that between date of silking of the inbreds and moisture percentage of the crosses.

Correlations were computed between the yielding ability of inbred-variety crosses and other characters of the inbred-variety crosses, including moisture percentage at husking, plant height, shank length, percentage of smut infection, ear length, rows per ear, good ears per plant, and shelling percentage With significant values at the .05 and .01 points of 0.188 and 0.246, respectively, the following significant positive correlations were obtained: Between yield and moisture content at husking, 0 3146; between yield and ear length, 0.5257; between yield and good ears per plant, 0.2117, while there was a negative correlation between yield and percentage of smut infection of −0.2155. Associations between the yields of inbred-variety crosses and plant height, number of rows per ear, and shelling percentage of the inbred-variety crosses ranged from −0.0234 to +0.0526, showing no significant association.

All possible correlations between 13 characters, 12 of these being characters of the inbred lines and the other being the yielding ability of the inbred-variety cross, were computed and the results are given in Table 6.

Ear length of the inbreds did not give a significant correlation coefficient with any other characters except yield index of the inbreds, pollen yield, and yield index of the inbred-variety crosses. Nearly all other interrelations between characters (Table 6) gave positive correlations of significant value. Date of silking of the inbreds was significantly correlated with all other characters except yield index of the inbreds and ear length. All of the measurable characters that represent growth vigor showed in general a positive association with each other. All 12 characters of the inbreds given in Table 6 gave positive and significant correlations with yield of the inbred-variety crosses and

TABLE 6.—*Total correlations between 12 characters of the 110 inbreds and yielding ability of inbred-variety crosses.*

Characters correlated*	2	3	4	5	6	7	8	9	10	13	14	15
Inbred 1	0.5118	0.6081	0.4819	0.6465	0.6193	0.5469	0.3831	0.3741	0.2230	0.0731	−0.0591	0.4742
Inbred 2	—	0.7560	0.4419	0.4817	0.4294	0.3959	0.2588	0.1855	0.3568	0.2549	0.0812	0.2717
Inbred 3	—	—	0.4324	0.5388	0.5025	0.4133	0.3522	0.3317	0.2201	0.1512	−0.0074	0.4110
Inbred 4	—	—	—	0.4954	0.4417	0.4797	0.3959	0.2893	0.1847	0.2040	0.0815	0.2889
Inbred 5	—	—	—	—	0.7623	0.5095	0.6013	0.4052	0.2085	0.1484	0.0352	0.4486
Inbred 6	—	—	—	—	—	0.5545	0.7424	0.3896	0.2894	0.1947	0.0320	0.5430
Inbred 7	—	—	—	—	—	—	0.5355	0.2384	0.2674	0.2065	0.1549	0.4069
Inbred 8	—	—	—	—	—	—	—	0.2559	0.2245	0.2025	0.0683	0.4463
Inbred 9	—	—	—	—	—	—	—	—	0.1990	−0.0029	−0.0342	0.1902
Inbred 10	—	—	—	—	—	—	—	—	—	0.3451	0.3202	0.2566
Inbred 13	—	—	—	—	—	—	—	—	—	—	0.6403	0.2474
Inbred 14	—	—	—	—	—	—	—	—	—	—	—	0.2768
Inbred 15	—	—	—	—	—	—	—	—	—	—	—	—

Significant value of r for P of .05 = 0.188
Significant value of r for P of .01 = 0.246

*Key to characters:
1 Inbred date silked
2 Inbred plant height
3 Inbred ear height
4 Inbred leaf area
5 Inbred pulling resistance
6 Inbred root volume
7 Inbred stalk diameter
8 Inbred total brace roots
9 Inbred tassel index
10 Inbred pollen yield
13 Inbred yield index
14 Inbred ear length
15 Inbred-variety cross yield

all exceeded the .01 point except the correlation between tassel index of inbreds and the yield of inbred-variety crosses.

A multiple correlation was computed between the yield of inbred-variety crosses and the 12 characters of the inbred lines given in Table 6. An R value of 0.6660 was obtained, while the value of R at the 1% point for degrees of freedom of 100, i.e., 3 greater than in the problem, was .470. Using the square of 0.660, or 0.4435, we may conclude that 44% of the squared variability in yield of the inbred-variety crosses was dependent upon the 12 characters of the inbred parents in the inbred-variety crosses.

It is generally known that there is a direct correlation, other things being equal, between length of growing season to maturity and yielding ability. The multiple correlation coefficient, holding constant date of silking, was calculated by means of a formula given by Tappan where

$$1\text{-}R^2_{15.2,3,4,5,6,7,8,9,10,13,14}\,\Big|\,1\,\Big| = \frac{1\text{-}R^2_{15.1,2,3,4,5,6,7,8,9,10,13,14}}{1\text{-}R^2_{15.1}}$$

A calculated value of R of 0.5310 was obtained showing that if date of silking is held constant that 28% of the total squared variability in yield of the inbred-variety crosses is directly related to the characters studied in the inbred lines other than date silking.

The breeding of improved inbred lines is of direct value in a corn breeding program as a means of reducing the cost of production of three-way and double crossed seed. Since there is a significant association as measured by the correlation coefficient between the characters of inbred lines that measure growth vigor and the combining ability of inbred lines in inbred-variety crosses, it would appear that the production of improved inbreds, as measured by the development of the inbreds themselves, will lead, on the average, to the development of higher yielding double crosses.

YIELDING ABILITY OF INBREDS IN F_1 CROSSES

Inbred lines that combined well in inbred-variety crosses were selected and their yielding ability in single crosses was studied in relation to their origin. All inbreds used in this study were selected by the pedigree method of breeding from single crosses between inbreds and subsequent selection during the segregating generations for vigor of plant, ability to withstand lodging, and resistance to smut.

Three groups of single crosses were grown, as described in the section on materials and methods, giving the pedigrees of the parents of a single cross in each of the three groups. Group I had no parents in common; group II had one parent in common; and group III had both parents in common.

Single crosses from each of the three groups were grown in randomized blocks, the Morris and University Farm strains of Minnesota No. 13 and the two early double crosses, Minhybrids 401 and 402, being included in each block. Two separate series of single crosses from inbreds with no parents in common were grown, or 43 crosses

in all. Fifteen single crosses and checks were grown in separate randomized blocks for groups II and III. Yielding ability of each of the single crosses in the three groups was compared with checks grown in the same randomized block. To determine whether the three groups of crosses were comparable from the standpoint of combining ability, the average combining ability of the inbred parents, for each of the single crosses, was determined by using the combining ability of each inbred as measured in an inbred-variety cross. Thus, as an illustration, the combining ability of A94×A99 was as follows:

Inbred Variety Cross	Percentage Yielding Ability	Percentage Moisture at Husking
A94×Minn. No. 13	115	123
A99×Minn. No. 13	102	98
Average	108.5	110 5

The average percentage yielding ability and moisture percentage at husking in inbred-variety crosses of the parents of each single cross in each of the three groups of single crosses is given in Table 7. The percentages used are on the basis of 100 for the average of two strains of Minn. No. 13, Minhybrids 401 and 402, which were grown in each of the four randomized blocks.

TABLE 7.—*Average percentage yielding ability and moisture percentage at husking in inbred-variety crosses of inbreds used in the three groups of single crosses differentiated on the basis of genetical origin*

Group	Number single crosses	Percentage combining ability	Moisture percentage
I	43	107 3	103 3
II	15	110.7	114.6
III	15	110.0	110.5

In general the three groups are of similar genetical value in combining ability, group I being somewhat earlier than group II or group III and somewhat lower in average combining ability.

Standard errors for yield in bushels per acre were computed separately for each of the four locations and for each of four randomized block trials. An average standard error was computed from analyses of variance, using the formula

$\frac{1}{4}\sqrt{S.E._{U.F.}^2+S.E._{Me}^2+S.E._{M}^2+S.E._{B}^2}$ where U.F., Me, M, and B refer, respectively, to University Farm, Meeker, Morris, and Breckenridge. This S.E. was then multiplied by $2\sqrt{2}$ to give a S.E. of difference that was accepted as of probable significance and that was used in interpreting the comparative yielding ability of the F_1 crosses. These S.E.'s for yield in bushels per acre and moisture content of ears at husking are summarized in Table 8.

In these yield trials two strains of Minn. No. 13 were grown and the two Minhybrids, 401 and 402. Minhybrids 401 and 402 have been outstanding in yielding ability in north central Minnesota. In the 2-year average in the commercial hybrid field trials as reported by

TABLE 8.—*Average standard errors for yield trials at four localities multiplied by $2\sqrt{2}$*

Number of parents in common of inbreds	Series of yield trials	$2\sqrt{2}$ S E.	
		Yield, bu.	Moisture content, %
0	1	5 5	1.5
0	2	4 9	1 4
1	3	5 3	1 5
2	4	5 2	1.7

Crim (1) for the test in Bigstone County in 1937 and in Ottertail in 1938, Minhybrid 401 gave the highest average yield of any of the hybrids tested and with lower moisture content than any hybrid except Minhybrid 402. In the group of hybrids considered to be adapted to the region, Minhybrid 402 was second to Minhybrid 401 in yield in bushels per acre In the only other commercial yield trial where Minhybrid 401 is well adapted, which was conducted in Meeker County for two years, 1937–38 inclusive, Minhybrid 401 led the five crosses that seemed adapted to the locality.

TABLE 9 — *Average yield in bushels and average moisture content at husking of Minhybrids 401 and 402 compared with Minn No 13 in each of four series of randomized block tests and at four locations, University Farm, St. Paul, Meeker Co , Morris branch station, and Breckenridge, 1938.*

Variety of cross	Yield in bushels for series					Moisture percentage for series				
	1	2	3	4	Av	1	2	3	4	Av.
Minhybrid 401	59 4	60.5	62 2	63.8	61 5	24 4	23 9	24 1	24 0	24 1
Minhybrid 402	52 8	55 7	54 9	55 0	54 6	21.8	20 8	22 3	21 5	21 6
U Farm No 13	53 6	52 0	55.9	50 8	53.1	28 5	27.8	29 6	29 7	28 9
Morris No 13	53 2	55 3	54 2	54 2	54 5	26 9	26 6	25 8	27.2	26 6

Minhybrid 402 was much earlier than Minn No 13 (Table 9) and yielded practically the same Minhybrid 401 yielded 12 8% more than the Morris strain of Minn. No. 13 and was several days earlier in maturity than the Morris strain and much earlier than the University Farm strain of Minn. No. 13. These two hybrids, Minhybrids 401 and 402, are therefore rather outstanding in yielding ability for early corn under the conditions of these trials.

The yielding ability and moisture content of each of the single crosses was expressed relative to the same characters for Minhybrids 401 and 402, the results being summarized in Table 10 in three groups differentiated on the basis of the origin of the original inbred lines.

The standard errors given in Table 8 were used as measures of significant differences and the single crosses were compared with Minhybrids 401 and 402. Cross A94×A99 in group I, for example, yielded 54.0 bushels with a moisture content of 25.5%. Minhybrid 401 yielded 59.4 bushels with a moisture content of 24.4%, while Minhybrid 402 yielded 52.8 bushels with a moisture content of 21.8%

TABLE 10.—*Comparison of single crosses with Minhybrids 401 and 402 on the basis of yield and moisture percentage at husking in yield trials at four localities in 1938.*

Origin of crosses	Not significantly lower in yielding ability than Minhybrid 401 or 402 and with moisture content at husking in four classes based on significant differences in moisture content				Significantly lower in yielding ability than Minhybrids 401 and 402
	Earlier than 402	Equal to 402	Equal to 401	Later than 401	
Group I...	2	12	12	2	15
Group II	—	—	3	3	9
Group III	—	1	—	—	14

In this trial differences of yield of 5.5 bushels and of moisture content of 1.5% were accepted as significant (Table 8). Hybrid A94× A99 was accepted as in the same group as Minhybrid 401 for yielding ability and moisture content at husking. Many of the single crosses were superior to the standard double crosses in yielding ability. In the summary there was no attempt to differentiate between those that were superior to Minhybrids 401 and 402 in yielding ability.

As will be noted from Table 10, 28 of 43 hybrids in group I were accepted as equal or superior to Minhybrids 401 or 402 and 15 were significantly lower in yielding ability, while 9 of 15 in group II were significantly lower in yielding ability than Minhybrids 401 and 402 and only 1 out of 15 in group III was accepted as equal to Minhybrids 401 and 402 in yielding ability and time of maturity.

These results are not greatly different from those reported by Wu (11). They show a direct relation between the origin of inbred lines and their combining ability in crosses as would be expected on the theoretical basis. It is also of interest to note that of 43 single crosses from crosses between unrelated inbreds, when inbreds are used that have previously proved to be good combiners as tested in inbred-variety crosses, that 28 of these, or 65%, were accepted as of equal yielding ability to double crosses known to be outstanding for the regions of the trials.

SUMMARY OF RESULTS

Inbred lines were bred by the pedigree method from crosses between inbreds where as a rule one parent at least of each cross was outstanding in ability to withstand lodging and in smut resistance. Selection during the segregating generations was made in selfed lines for plant vigor, smut resistance, and ability to withstand lodging. Evidence was given to show the extent to which the inbreds were improved in various characters and, in general, the methods used appeared to lead to distinct improvement in many characters.

The inbreds produced by the pedigree method were studied in inbred-variety crosses to determine their combining ability. The evidence as given indicates that lines of good combining ability are obtained more frequently from crosses between inbreds that them-

selves are good combiners than from crosses between inbreds that are low in combining ability. Combining ability, therefore, is an inherited character.

Fourteen characters of inbreds, many of which were related to growth vigor, were studied for a 3-year period in small replicated plats with two replications. Correlations were calculated to show the relationship between certain characters of the inbreds and of the inbred-variety crosses. These included date of silking of the inbreds and moisture content at husking of inbred-variety crosses, while plant height, smut percentage, ear length, and shank length of the inbreds was correlated with the same characters in inbred-variety crosses. Correlation coefficients, based on 110 strains, ranged from 0.3677 for plant height to 0.5746 for maturity, all exceeding the 1% point for level of significance.

Twelve characters of the inbreds, by means of total correlations, were found to be significantly related to yielding ability in inbred-variety crosses. The correlations ranged from +0.1902 for tassel index of inbreds and yield of inbred-variety crosses to +0.5430 for root volume of inbreds and yield of inbred-variety crosses. In these studies the significant values of r for a P of .05 and .01, respectively, were +0.188 and +0.246, all coefficients exceeding the 1% point except the correlation between tassel index and yield.

A multiple correlation coefficient of .6660 was obtained for association between yield of inbred-variety crosses and the following characters of inbred lines, date silked, plant height, ear height, leaf area, pulling resistance, root volume, stalk diameter, total brace roots, tassel index, pollen yield, yield index, and ear length. When date of silking was held constant a partial multiple correlation coefficient of .5310 was obtained for the correlation between inbred-variety yield and 11 other characters of the inbreds.

Inbreds of good combining ability were selected from inbred-variety crosses. These inbreds were obtained by the pedigree method of breeding. They were studied in F_1 single crosses in three groups. Group I where the inbred parents for each single cross were selected from crosses between inbreds in such a manner that there were no parents in common in the ancestry of the single cross; group II with one parent in common; and group III with both parents in common. On the average, the F_1 crosses in group I were superior in yielding ability to those in group II and far superior to those in group III. From 43 single crosses in group I, 28 were not significantly lower in yielding ability and moisture percentage to Minhybrids 401 or 402, while similar relationships for group II and group III gave 6 out of 15 and 1 out of 15, respectively, that were not significantly lower in yielding ability and moisture percentage than these double crosses.

LITERATURE CITED

1. Crim, R. F. Minnesota hybrid corn field trials, 1938. Univ. Minn. Ext. Pamphlet 57. 1939.
2. Davis, R. L. Report of the plant breeder. Porto Rico Agr. Exp. Sta. Ann. Rpt., 1927:14–15. 1929.
3. ———. Maize crossing values in second-generation lines. Jour. Agr. Res., 48:339–359. 1934.

4. HALL, D. M. The relationship between certain morphological characters and lodging in corn. Minn. Agr. Exp. Sta. Tech. Bul. 103. 1934.
5. JENKINS, M. T. Methods of estimating the performance of double crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.
6. ———— and BRUNSON, A. M. Methods of testing inbred lines of maize in crossbred combinations. Jour. Amer. Soc. Agron., 24:523–530. 1932.
7. JONES, D. F. The effects of inbreeding and crossbreeding upon development. Conn. Agr. Exp. Sta. Bul. 207. 1918.
8. RICHEY, F. D. The convergent improvement of selfed lines of corn. Amer. Nat., 61: 439–449. 1927.
9. ———— and SPRAGUE, G. F. Experiments on hybrid vigor and convergent improvement in corn. U. S. D. A. Tech. Bul. 267. 1931.
10. TAPPAN, M. On partial multiple correlation coefficients in a universe of manifold characteristics. Biometrica, 19:39-44. 1927.
11. WU, SHAO-KWEI. The relationship between the origin and characters of selfed lines of corn and their value in hybrid combination. Jour. Amer. Soc. Agron., 31:131-140. 1939.

NOTES

AN APPARATUS MADE FROM GLASS FOR THE CONTINUOUS WATERING OF POT CULTURES[1]

FOR experiments pertaining to the study of the effect of such minor elements as I, Mn, Cu, Zn, B, etc , upon the growth and development of plants, it is essential to use cultures to which have been added mineral nutrients of known composition. Any contamination of the cultures with the particular elements under study would cause an error. Not only must the mineral nutrients be carefully analyzed, but also metal-free water must be used with the experiment. This means that any method of watering the pots must be one in which no metal is allowed to come in contact with the water at any time Water must be handled in glass or silica containers.

Water may be added manually to the pots, daily weighing the pots to determine the loss of water and adding enough water to bring the culture to the desired level of water content This requires considerable time and trouble on the part of the investigator, especially if he is handling a large number of pots.

An improved and simplified apparatus for watering experimental pot cultures in greenhouse work has been constructed by the authors. The apparatus is an improvement of the form previously reported by Calfee and McHargue.[2]

It makes use of the capillary action of sand or soil and provides a constant supply of water in each pot, regardless of how fast the water is transpired by the plants The apparatus can be constructed entirely of glass by anyone who has had some experience in glass blowing. With the exception of the reservoirs, which are soft glass bottles, and a 250-cc beaker, pyrex glass tubing is used.

A diagram of the assembly of the apparatus is shown in Fig. 1. The bench (1) supports 1-gallon glass bottles (2) which are used as

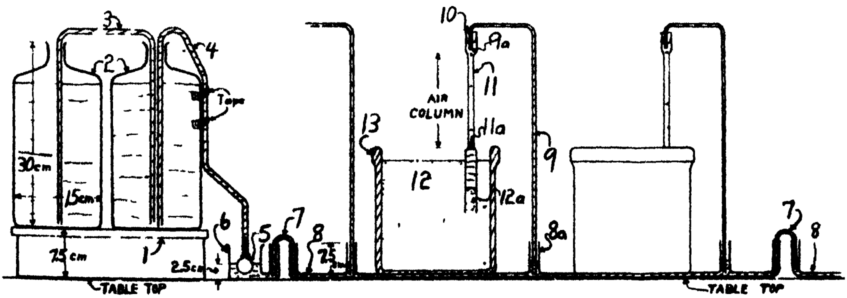

FIG. 1.—Diagram of apparatus.

[1]The investigation reported here was carried out in connection with a project of the Kentucky Agricultural Experiment Station, Lexington, Ky., and is published by the permission of the Director. Read before the Division of Chemistry, at the 26th annual meeting of the Kentucky Academy of Science, Murray State Teachers College, April 28, 1939.

[2]CALFEE, R. K., and McHARGUE, J. S. An automatic watering system for pot cultures. Jour. Amer. Soc. Agron., 29:797. 1937.

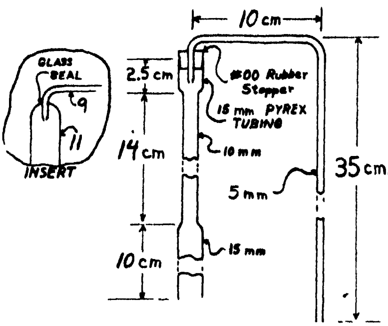

FIG. 2. - Showing dimensions and detail of float.

water reservoirs. Two or more of the bottles may be connected by means of siphons (3) constructed of 7-mm pyrex tubing. A siphon (4) made of the same size tubing is inserted in one of the bottles and held in place by adhesive tape or paper stickers on the side of the bottle. At the lower end of this tube is a pyrex glass float (5) which operates a ground needle-valve arrangement. Dimensions and greater detail of this float are shown in Fig. 2. This float maintains a constant level of water in the 250-cc beaker (6). This water level is 2.5 cms above the table top and is the same in the tube (8) which is connected to the beaker by means of the side tube (6a) and siphon (7).

The tube (8) is the "main" for the system. It is made with vertical side tubes (8a) spaced the same distance as one wishes between centers of adjacent pots (13). The pots are filled with purified sand (12) of rather fine grain. The watering tube (11) is placed in the sand as indicated and connected by means of the siphon (9) and rubber stopper (10) to the "main" tube. Details of tubes (9) and (11) are shown in Fig. 3. The stopper (10) holding (9) is placed tightly in the tube (11) so that when (9) is filled with water and water drips from the tip (9a) the water level in (11) is at (11a). The height of the air column in (11) is adjusted at 15 cms and referring to the curve in Fig. 4, which has been experimentally determined, the water content of the sand will be 23.7 grams per 100 grams of sand.

The position of the curve in Fig. 4 is determined by the kind of sand or soil in the pot. The curve illustrated indicates, for one type of sand, the water content in one gallon pot (containing 4 kiolgrams of sand) for a particular height of air column in (11). The water content of the pot can be set, within a limited range, by adjusting the height of this air column. If one desires to eliminate the stopper (10), which incidentally does not come in contact with water, he may do so by sealing (9) and (11) together as

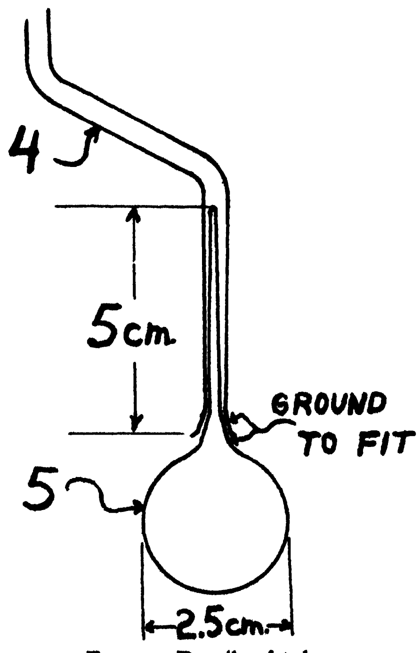

FIG. 3.—Details of tubes.

indicated in the insert in Fig. 2. This type of tube is more clumsy to handle and much more susceptible to breakage.

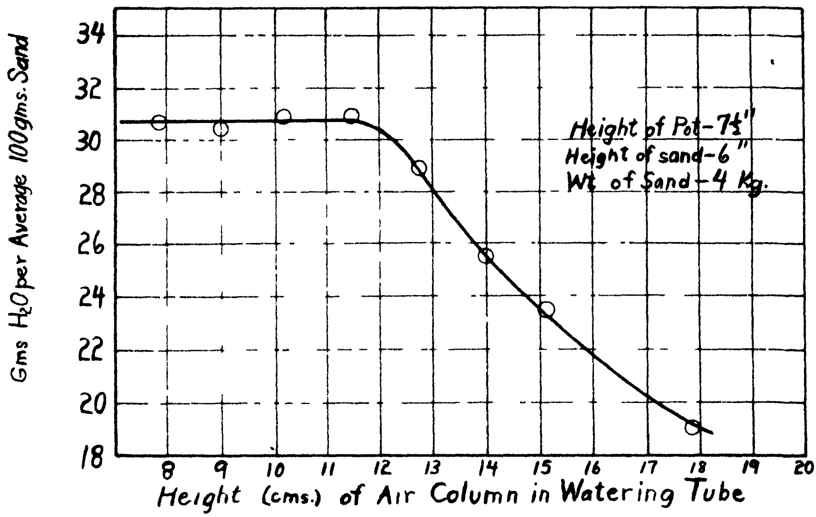

FIG. 4.—Curve showing water content in a pot of sand for a particular height of air column in the tube.

The action of the apparatus is as follows: In effect the tubes (9) and (11) combined are a siphon. Capillary action of sand in the pot creates a force which pulls the water up the tube (9). This force is dependent upon the amount of water in the sand. Low water content in the sand permits the sand to exert a greater force. If the air column in the watering tube is short, more water will be drawn over by the sand until the force diminishes to the point that it is just sufficient to hold a column of water the same height as the air column. As water is absorbed by a plant in the sand or evaporates, the force increases and water drips from the tip (9a). Water in the lower part of (11) stands at the height (11a) and is in contact with sand (12a) at the bottom of the tube. Water is absorbed from the system by the sand at this point.

Occasionally an air leak will occur around the stopper (10) or the base of (11) which normally is sealed by wet sand (12a). If the siphon is broken, the tube must be refilled with water and the leak corrected before normal operation can be resumed. This is accomplished by removing the stopper (10) and filling (11) with distilled water to a point determined by experiment so that when the air is drawn out of (9) into (11) the level (11a) will be the correct distance from (9a). Only a few seconds are required to make this adjustment. Normal operation of the watering apparatus is evident by the dripping of water from the tip (9a).

The efficiency of this type of apparatus in supplying water to the cultures was shown by Calfee and McHargue in the above-metnioned report. This watering apparatus has functioned satisfactorily during

the growth from seed to maturity of a few species of plants. It eliminates the necessity of weighing the pots and maintains a uniform water content in the cultures during the time the plants are making their growth A single worker need not spend more than half an hour daily in watering as many as 100 pot cultures growing simultaneously. —E. B OFFUTT, R K CALFEE, AND J. S. MCHARGUE, *Dept of Chemistry, Kentucky Agricultural Experiment Station, Lexington, Ky.*

A METHOD OF INDUCING AN EPIPHYTOTIC OF RUST IN GRAIN BREEDING NURSERIES

IN order that selections for rust resistance in the small grains can be made satisfactorily, it is important that the disease be present uniformly and in considerable abundance Frequently, nature unaided does not provide conditions suitable for bringing about the desired amount of infection. Some years the disease appears so late in the season that there is little opportunity to make selections and in some sections natural infection does not always occur. Furthermore, since it has been demonstrated that rust resistance in cereals may vary with the stage of growth, it seems very desirable to establish rust in breeding nurseries as early in the season as practical. The method described below has been used successfully for the past three years in producing an earlier, more uniform, and more severe outbreak of crown rust in the oat nursery at the Georgia Experiment Station.

All alleyways and borders are planted with one drill width (about 4 feet) of a rust-susceptible variety like Winter Turf. Plants of this sus-

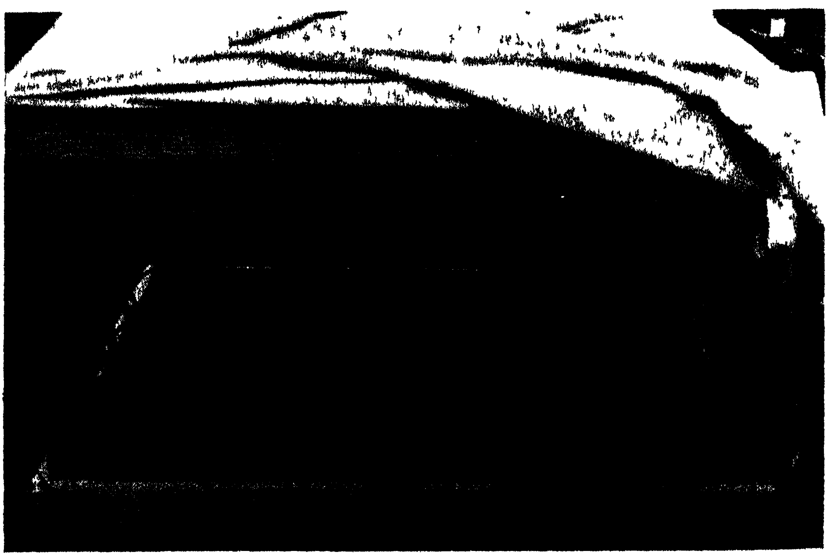

FIG. 1.—Cloth-covered frame enclosing rusted plants. Crown rust infection on Winter Turf oats in this border was so severe that the oats failed to head.

ceptible variety are heavily infected with rust by artificial inoculation in the greenhouse during late winter and these plants are then set at intervals throughout the borders in early spring. Approximately 16 square feet space about the rusted plants is then covered by a wood frame 4 feet square and 2 feet high. The frame is covered with cotton sheeting. Fig. 1 shows one of these frames in position in the field.

Late in the evening of each of several succeeding days the ground within and immediately surrounding this frame is watered and the cloth covering is draped down on all sides and thoroughly wetted. The frame then serves as a moist chamber and maintains atmospheric conditions quite favorable for infection and spread of rust. It also affords protection to the transplanted plants from spring frosts. After the plants growing on the area covered have been inoculated, the frames may then be moved to other locations. Only a few infection centers are necessary if the rust-susceptible variety occurs frequently in the planting order

Rust infection induced in the manner described, especially when started early in the season, usually spreads rapidly from these infection centers through the rust-susceptible border variety if later conditions are at all suitable. Usually a very general prevalence of rust infection may be established in the breeding nursery while nearby fields show little or no rust. While this method of inducing an artificial epiphytotic of rust has only been applied in connection with the oat breeding program, the author believes that it may very well be employed in initiating early infection of those rusts attacking other grains.— S. J. HADDEN, *Georgia Agricultural Experiment Station, Experiment, Georgia.*

A METHOD OF PREPARING SOME NATIVE GRASS SEEDS FOR HANDLING AND SEEDING[1]

THE reestablishment of grass on barren range and on abandoned cultivated lands is of increasing interest and importance throughout the Great Plains. The lack of sufficient adapted, introduced, or cultivated species makes it desirable to use native grass species. One of the most serious problems in the handling of these species is seed character. For species to be useful in the regrassing program, it should be possible to seed them through the ordinary grain drill. If this is not possible, the species can be of only minor value.

Several of the more important species of native grasses have seed characters that make them difficult to clean and virtually impossible to seed with standard drill equipment. Some have long awns, and some have a combination of awn and various types of pubescence on the seed coat.

An attempt has been made to treat mechanically some grass seeds for the removal of awns and hairs. A hammer mill was first used in

[1]This paper is a contribution from the U. S. Department of Agriculture, Soil Conservation Service Nursery Section, on work done at Mandan, North Dakota, in cooperation with J. T. Sarvis, Bureau of Plant Industry, Division of Dry Land Agriculture, and George A. Rogler, Division of Forage Crops and Diseases, at the Northern Great Plains Field Station, Mandan.

connection with the cleaning of grass seed in 1935.[2] Recent trials at the Soil Conservation Service Nursery at Mandan, North Dakota, indicate that the method is economical and also practical from the standpoint of seed improvement.

The method described below was devised to overcome sufficiently the difficulties in seed character in order to allow passage of the seed through the ordinary drill. The equipment used was the ordinary seed cleaning equipment, chiefly thresher and fanning mill, plus a hammer mill.

The hammer mill is of somewhat different design than that ordinarily used. The hammers are straight, thin bars of iron, lacking the articulated head which is usual in commercial machines. They are swung freely from a triangular frame, and clear the screen sufficiently so that there is no cutting or mashing action between them. The hammers at the intake are short and are graduated to a greater length toward the outlet, with the result that the hammering process grows more severe as the materials pass further through the body of the machine The screen area is large, and screens are available in 13 sizes, from 1/40-inch to 1-inch openings. The chief advantage of this mill over some others is that it will operate at low speeds.

The seed was passed through the hammering process either from the thresher or from the fanning mill. The process was varied by changing the screen, the speed of the operation, and the amount of material held on the screen. It was fundamentally the same for all species, the difference lying in the kind and amount of material to be removed (Table 1).

SPECIES PROCESSED

Big bluestem.—Big bluestem (*Andropogon furcatus*) is awned, has ciliate pedicles, and a sterile pedicellate spikelet. The hammering removed a high percentage of the awns, the pedicellate spikelet, and part of the cilia. Recleaning once was sufficient after processing.

Blue grama.— The blue grama (*Bouteloua gracilis*) spikelet is composed of an awned fertile floret and an awned, densely bearded, rudimentary floret. It was cleaned roughly to remove the stems and other coarse waste before treating. The mill removed most of the rudiments and awns and polished the seed.

Indian ricegrass.—The problem with Indian ricegrass (*Oryzopsis hymenoides*) was somewhat different from that encountered in handling most species. The awn is readily deciduous and the callus is long pilose with silky white hairs 3 mm long. The glumes cling to about 50% of the seed, as do portions of the slender panicle branches. The processing in this species must be carefully controlled to prevent breakage of the seed; but the hairs, glumes, and parts of the panicle can be removed entirely. After one run through the hammer mill, the seed was screened and fanned. This separated the seed which was completely free of hairs. That portion not completely clean was re-run through the hammering process. As the seed is heavy and smooth and of a regular shape, the purity can be raised to very nearly 100%

[2]Work done at Soil Conservation Nursery, Ames, Iowa, by G. L. Weber, under the direction of Jess L. Fults.

TABLE I.—*Results of process on purity, weight per bushel, and seeding properties of various species*

Species	Purity %*		Weight per bushel, lb.		Value for seeding through a grain drill			
					Before treatment		After treatment	
	Before treatment	After treatment	Before treatment	After treatment	Low rate	Desirable rate	Low rate	Desirable rate
Agropyron cristatum†	—	—			Good	Excellent	—	—
Andropogon furcatus	70.0	94.1	9.0	23.0	None	None	Fair	Good
Bouteloua curtipendula	20.0	86.0	7.5	24.5	None	Poor	Excellent	Excellent
Bouteloua gracilis	86.0	91.0	7.5	23.0	None	None	Poor	Good
Elymus canadensis	75.0	94.0	7.5	24.0	None	None	‡	‡
Elymus junceus	98.0	99.0	15.0	19.0	None	Poor	Good	Excellent
Oryzopsis hymenoides	90.0	99.4	23.5	53.5	None	Poor	Excellent	Excellent
Stipa viridula	80.0	95.0	31.0	33.0	None	Poor	Excellent	Excellent

*Purities given in both columns are those obtained within reasonable limits of economy with a fanning mill of commercial type.
†*Agropyron cristatum* does not enter into treatment trials but is included as a standard for judging seeding value.
‡This species not included in drilling trials.

by the polishing, even though it is not fanned after threshing and before hammering.

Sand reed grass.—Sand reed grass (*Calamovilfa longifolia*) presented a problem comparable to Indian ricegrass and has been treated with the same good results.

Canada wild-rye.—Canada wild-rye (*Elymus canadensis*) has the longest awn of any of the species treated. It is not only impossible to drill this seed before processing, but it is difficult to clean it. The treatment removed the awns almost completely. The palea and lemma are fastened tightly to the caryopsis and are not removed by the treatment. After hammering, the seed was easily cleaned to a good purity by screening and fanning. Ordinarily it is not necessary to pass this seed through the fanning mill before processing.

Russian wild-rye.[3]—Russian wild-rye (*Elymus junceus*), an introduced species, was first tried at this station about 10 years ago and is now receiving considerable attention. It has a short, sharp awn, and stiff bristles on palea and lemma. It threshes and cleans easily but is most difficult to seed through a grain drill. Processing polished the seed, removed most of the awns and bristles, and allowed it to flow easily through the grain drill.

Side-oats grama.—Side-oats grama (*Bouteloua curtipendula*) is awnless, but the five to eight spikelets are not deciduous from the rachilla, the whole spike falling together. The processing broke up the spike into individual spikelets and freed some caryopses. Recleaning removed empty glumes, rachilla joints, and empty spikelets. Processed seed used on about 5 acres has given a very even stand, the seeding being done with a four-row plate nursery seeder.

Green needle grass.—The awn in green needle grass (*Stipa viridula*) is about 50% deciduous in threshing. In addition to the awn, there are present fine white callus hairs which keep the seed from feeding into the drill cups. The processing removed all the awns, polished the

TABLE 2.—*Results of process on germination of seed within the first six months after processing.*

Species	Treatment	Germination, %*		
		Dec. 1, 1938	Feb 1, 1939	Mar. 1, 1939
Andropogon furcatus (7 lots)	Untreated	40.3	40.0	30.0
	Treated†	48.0	38.7	48.6
	Caryopses‡	58.5	71.0	77.8
Bouteloua curtipendula (5 lots)	Treated†	53.0	60.5	65.5
	Caryopses‡	54.2	66.7	67.2
Bouteloua gracilis (3 lots)	Untreated	67.0	75.0	67.6
	Treated†	83.0	79.0	80.3
	Caryopses‡	82.5	84.6	80.3

*Seed processed in September and October.
†"Treated" defined as caryopsis with palea and lemma intact.
‡Caryopses freed from palea and lemma in processing.

[3]The use of "Russian wild-rye" as a common name for *Elymus junceus* is unofficial.

seed, and removed enough of the pubescence to allow the seed to slide easily in the drill. It was rough-cleaned over the fanning mill before polishing, and recleaned afterward.

The cost of this process is so low that it is not a factor in comparison to the improvement in quality of the seed. The loss of total weight in treating a lot of seed was very marked, but there was little actual loss of filled florets. There was, however, a possibility that some or all of the species would suffer a decrease in viability through the violence of the treatment. This was particularly true where caryopses were removed. Germination data indicate no change immediately after processing, and stored samples germinated throughout the winter showed no loss in viability of the cleaned caryopses six months after treatment.

The results shown in Table 2 are average figures for the larger lots handled. The three species shown are those in which caryopses are freed in the process and which would therefore be expected to show changes in germination. All germinations shown were made in soil in the greenhouse at an approximate soil temperature of 30° C.—G. L. WEBER, *Mandan, N. D*

CHROMOSOME NUMBER IN DWARF OATS

A STUDY of the chromosome number of five varieties of dwarf oats is reported These drawfs are known under the names Trelle, Denton, Prolific, Early White, and Early Black (C. I. Nos. 3634, 3635, 3636, 3637, and 3638, respectively).[1] They may be divided into two groups, as the Trelle and Denton dwarfs have short, abnormal, compact panicles with very thick, stiff, tough culms. The other three are true dwarf oats and have panicles and stems similar to those of normal oats, although shorter and smaller. Information on the origin, characters, etc , of these dwarfs appears in the literature.[2]

The desirability of using the Trelle and Denton dwarfs in crosses with varieties of normal stature for the purpose of deriving agronomic varieties of oats having stiffer straw and greater standing ability makes the determination of their chromosome number relevant. Attempts to cross these dwarfs on varieties of normal height thus far have been unsuccessful. Consequently specimens were collected for the writers at the Aberdeen Substation, Aberdeen, Idaho, by Harland Stevens and Ogden C. Riddle and forwarded to Washington for cytologic examination of the pollen mother cells by the senior writer.

In all five varieties 21 bivalent chromosomes were found at diakinesis. Fig. 1, A-D, shows the chromosomes in four of these five varieties. It was not unusual to find in some pollen mother cells chromosome abnormalities such as are shown in Fig. 2, B, E. These

[1]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

[2]STANTON, T. R. Prolific and other dwarf oats. Jour. Heredity, 14:301–305. 1923.

————. Superior germ plasm in oats. U. S. D. A. Yearbook 1936:347-414. 1936.

DERICK, R. A. A new "dwarf" oat. Sci. Agr., 10:539–542. 1930.

ATKINS, I. M. and DUNKLE, P. B. A dwarf oat found in a Nortex-Victoria cross. Jour. Amer. Soc. Agron., 30:347–348. 1938.

two photo-micrographs illustrate the occasional failure of one or more chromosomes to be included within the metaphase plate. In the varieties Early White and Prolific such abnormalities seemed more prevalent than in the other three varieties It is quite possible that

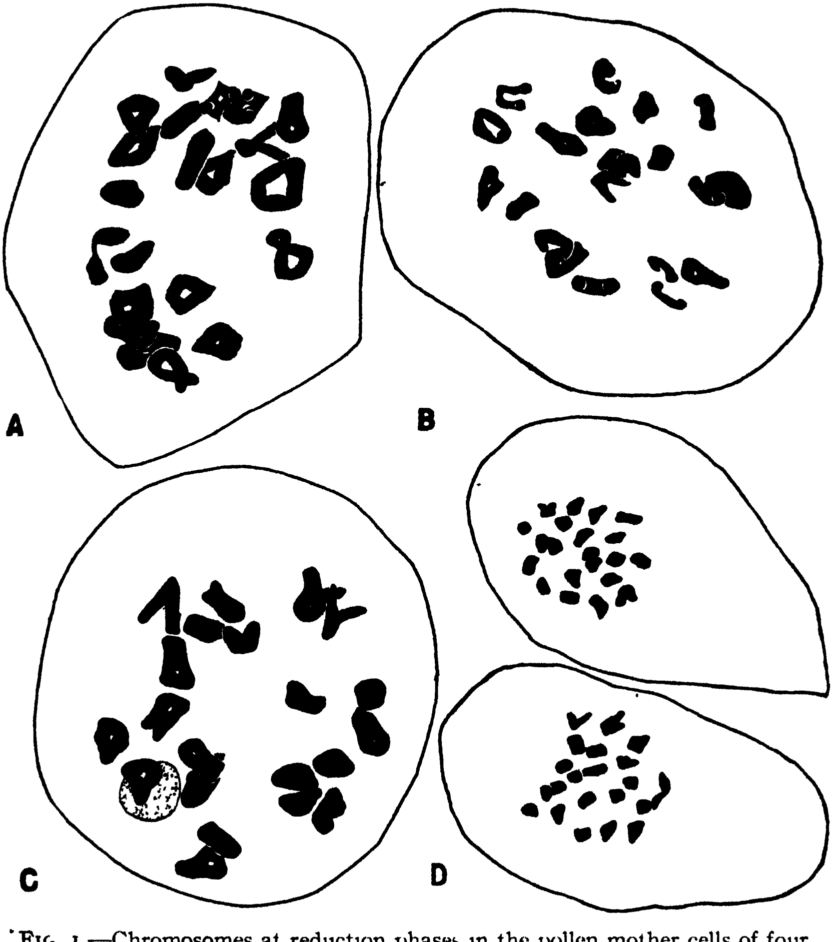

FIG. 1.—Chromosomes at reduction phases in the pollen mother cells of four dwarf oat varieties: A, diakinesis in Prolific dwarf; B, diakinesis in Trelle dwarf; C, diakinesis in Denton dwarf; D, second metaphases in Early Black dwarf.

these irregularities in meioses were due to an abnormal environment at the time the material was collected. The majority of the pollen mother cells in all five varieties distributed their chromosomes, in the reduction phases, equally to the daughter cells. Fig. 2, A, C, D, and F, shows several phases in which the chromosome behavior is normal.

In conclusion, no chromosomal incompatibilities appear to exist that might prevent hybridizing the Trelle and Denton dwarfs with oats of standard stature for the purpose of transferring their desirable

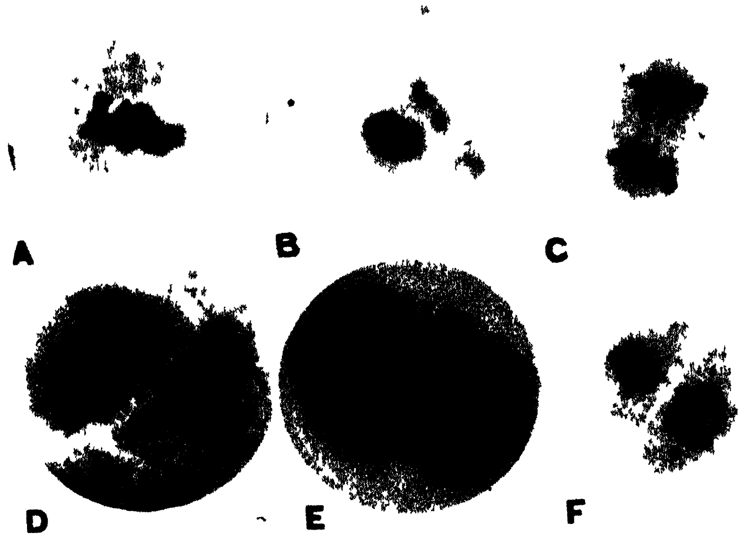

FIG. 2. Photomicrographs of normal and abnormal reduction phases in the pollen mother cells of dwarf oat varieties. A, normal first metaphase plate of Early Black dwarf; B, abnormal first metaphase plate of Prolific dwarf; C, normal first anaphase of Prolific dwarf; D, normal second division phases in Prolific dwarf; E, abnormal second metaphases in Prolific dwarf; F, normal second division phases in Early White dwarf.

straw characters to commercial varieties.—A. E. LONGLEY AND T. R. STANTON, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

THE CROP-PRODUCING VALUE OF VETCH ROOTS[1]

VETCH is grown primarily to increase the yield of the corn or cotton crop which follows after turning under the vetch. The increase in yield of crops following vetch is due largely to the nitrogen taken out of the air by the vetch.

Experiments conducted at the Mississippi Agricultural Experiment Station show that the roots of vetch contain 35% of the nitrogen in the whole plant. In other words, if the entire tops of vetch are removed level with the top of the ground, more than one-third of the nitrogen which the vetch contains will be left in the soil.

The crop-producing value of vetch roots is shown by the following data:

	Yield of corn, bu. per acre
No vetch	15.9
Vetch turned under	33.1
Vetch with tops removed	23.3

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Published with the approval of the Acting Director as Journal Article No. 20 N. S.

The vetch roots increased the yield of corn 7.4 bushels. Where the tops were also turned under an additional 9.8 bushels of corn were obtained. The test was conducted on Ruston fine sandy loam. The plats were 1/35 acre in size, and there were nine replications.

In this test the vetch was scraped off with a hoe and all of the tops removed. Where vetch is cut for hay, some of the tops will be left on the ground and, on the basis of the data presented, these tops together with the roots will probably increase the yield of corn a little better than half as much as where the whole vetch plant is turned under. In other words, cutting vetch for hay will leave half of its crop-producing value in and on the soil for corn production.

Similar or better results can probably be obtained when the vetch is grazed off by livestock as when cut for hay.—W. B. ANDREWS, *Agricultural Experiment Station, State College, Miss.*

A SAMPLER FOR SURFACE SOILS

IN taking samples of surface soil for moisture determination or for chemical analysis it is desirable to take a uniform core of soil from the surface to a given depth. In cultivated soils this is impossible with an auger because the dry soil at the surface falls away and the resulting core is not representative of the surface soil as it existed in the field Samples obtained with a spade are too large to handle, and if an aliquot is taken, a serious error may result from improper mixing before taking the aliquot.

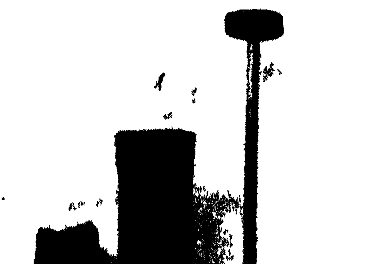

FIG. 1 —A sampler for surface soils. The core drops out readily when the tube is inverted.

A tubular sampler seems to be the best tool for this purpose and many such samplers have been described in the literature. The sampler herein described varies from the usual tubular type in that the bore is not uniform throughout This arrangement eliminates some of the difficulties encountered with the uniform bore sampler.

In a tubular sampler of uniform bore the friction on the walls causes a compaction in the core which tends to push the core downward instead of cutting it cleanly and without disturbance. Errors in sampling are thus introduced. Furthermore it is difficult to remove the core from such a tube. This difficulty has been only partially overcome by cutting a slot in the side of the tube for a portion of the length. This arrangement has a disadvantage in that it weakens the tube.

The sampler illustrated in Figs. 1 and 2 was made from a 1¾ by 8 inch steel shaft. The first step was to drill a 1¼ inch hole through the center of the shaft. Next the bore was increased to 1 5/16 inches from the top to within ½ inch of the bottom of the tube. By means of a still larger drill the bore was then increased to 1 11/32 inches for a distance of 4 3/8 inches from the top of the tube. The outside walls were then turned down to the dimensions shown in Fig. 2. Calibrations 1 inch apart were placed on the outside of the sampler to make it possible to take samples to a uniform depth. A ¼-inch hole was drilled through the top. A rod passed through this hole makes it easy to turn the tube as it is forced into the soil

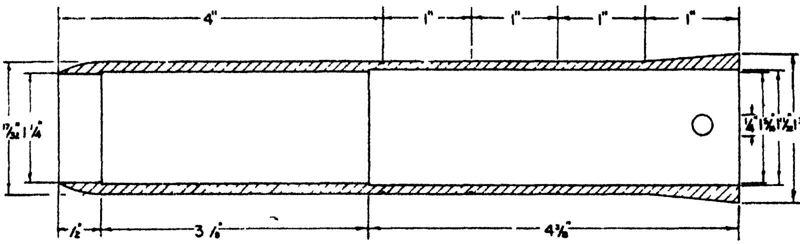

FIG. 2 Sectional diagram of surface soil sampler.

This sampler, constructed as described, has proved to be very durable Fine-textured soils have been sampled when they were so dry that the sampler had to be driven into the soil by means of a hammer. The driving cap shown in Fig. 1 was made for this purpose. The heavier wall in the upper 1 inch of the tube was found to be necessary to avoid injury to the tube when being driven into dry soil. The lower end of the tube, turned down to form a cutting edge was tempered slightly.

When the sampler is turned or driven into the soil the core is not depressed and, except in the case of wet clay soils, it drops out readily when the tube is inverted. The plunger shown in Fig 1 was designed to aid in removing the core from the sampler, but it is only required when the soil is wet and very sticky. The ease with which the core may be removed makes it possible to take a large number of samples in a short time.—R. L. COOK AND B. J. BIRDSALL, *Michigan State College, East Lansing, Mich.*

WEATHER IN RELATION TO YIELD OF AMERICAN-EGYPTIAN COTTON IN ARIZONA[1]

IN studies incidental to a survey of production trends of American-Egyptian cotton the annual fluctuations in yields of this extra long staple cotton were compared with maximum, minimum, and average temperatures, with percentages of relative humidity, with dates of killing frost, and with evaporation. Of these six weather phenomena only date of killing frost and evaporation showed any consistent relationship with yield.

[1]Contribution from the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

The final yield of cotton is undoubtedly affected by complex interactions of many weather factors. The indirect effects of weather on cotton yields may be almost as important as the direct effects by favoring, or retarding, the reproduction of harmful insects and the progress of diseases. Also, soil fertility, amount of irrigation water used, method or time of irrigation, insect damage, plant diseases, and frequency of picking are all factors that affect yield. When comparing one weather factor with yield a high correlation can not be expected because one or more of the other factors affecting yield may be counteracting the effects of the phenomenon under consideration.

The length of the growing season is distinctly one of the limiting factors in the production of high yields of Pima cotton in Arizona. Fig. 1 shows the number of days from September 30 to killing frost at Sacaton, Arizona, in comparison with the average yields of American-Egyptian cotton in Arizona from 1918 to 1938, inclusive. The chart shows that in seasons when frosts are early yields are low, and in years when frosts are late yields are high, with very few exceptions to the general trend.

Evaporation is the result of several interacting weather factors, namely, temperature, wind velocity, atmospheric humidity, and sunshine. Fig. 2 shows the average annual yields of American-Egyptian cotton for the 21 years from 1918 to 1938 in comparison with the total evaporation for the months of July and August. Evaporation was measured at Sacaton in an open tank of the type used for many years

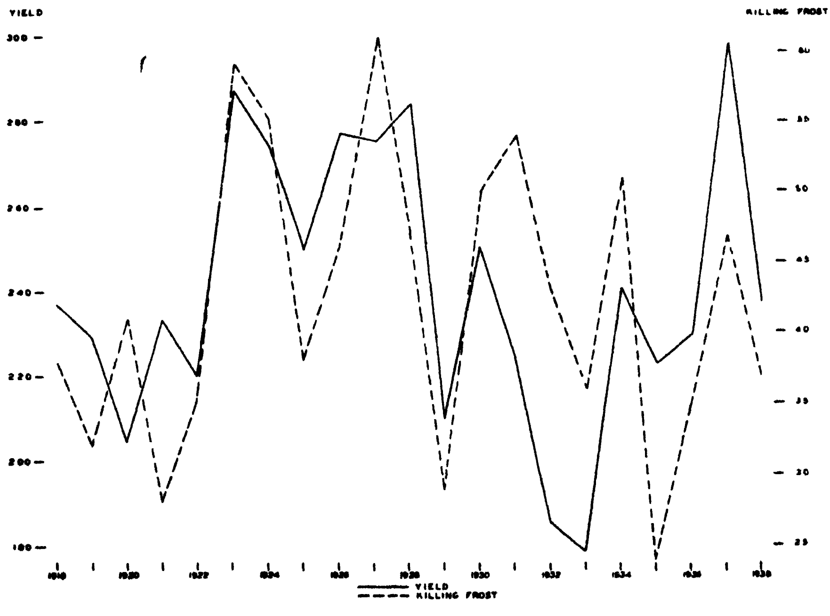

FIG. 1.—Yields per acre, in pounds of lint, of American-Egyptian cotton for Arizona and number of days from September 30 to the first killing frost at Sacaton, Arizona, for the years 1918–1938, inclusive. The value of the correlation coefficient, +.574, is above the 1% level of significance.

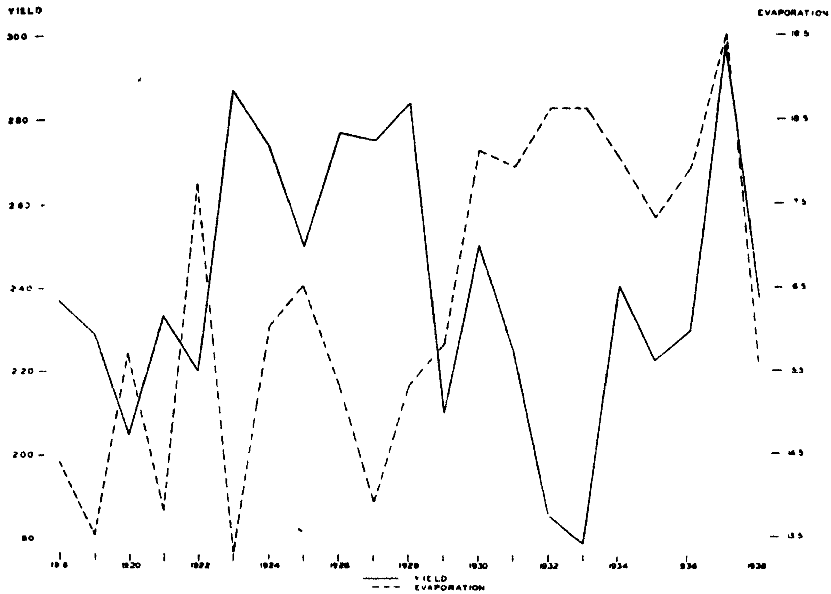

FIG. 2. Yields per acre, in pounds of lint, of American-Egyptian cotton for Arizona and evaporation, in inches, during July and August from an open tank at Sacaton, Arizona, for the years 1918–1938, inclusive. The value of the correlation coefficient, –.296, is not significant. When the data for the very exceptional season of 1937 are excluded, the value of the correlation coefficient for the remaining 20 comparisons is raised to –.562, which is on the 1% level of significance.

at stations of the Bureau of Plant Industry. The months of July and August cover practically all of the effective flowering period of Pima cotton in Arizona.

In some districts a crop of Pima cotton is grown with as little as 4 acre feet (48 acre inches) of irrigation water, including that applied at planting time. The average July and August evaporation for these 21 years is 16.3 inches, or approximately one-third of the amount of water some farmers use in the entire growing season. In 1931, 1932, 1933, and 1937 evaporation in July and August averaged 18.6 inches. With the exception of 1937 the average yield in each of these years was much below the 21-year average. The correlation of yield with evaporation during flowering period for the 21 available comparisons is so low that it has no statistical significance. On the other hand, when the data for the very exceptional season of 1937 are excluded, the data for the remaining 20 years give an *r* of –.562, a highly significant negative correlation. A value of –.800 is obtained for a partial correlation of yield with evaporation (frost constant) for the same 20 years.

Assuming that the factors promoting excessive evaporation during the flowering period also tend to reduce the yields of cotton, it seems reasonable to believe that heavier or more frequent irrigations may

counteract, at least in part, the ill effects of these factors. However, if irrigation water in excess of the optimum is applied the ill effects of over-irrigation might entirely offset the benefits to be derived from the practice of increasing irrigations during seasons of excessive evaporation.

In conclusion, data are presented which show that early killing frost in the fall and high evaporation during the flowering period are two of the weather factors which appear to limit yields of American-Egyptian cotton in Arizona. Increased irrigation during the critical flowering period, within reasonable limits, is suggested as a means of counteracting the effects associated with high evaporation.—H. J. FULTON, *U. S. Field Station, Sacaton, Arizona.*

AGRONOMIC AFFAIRS

CALIBRATING QUICK CHEMICAL SOIL TESTS

THE Soil Testing Subcommittee of the Fertilizer Committee of the American Society of Agronomy has assembled a series of 30 soils from 15 states for the purpose of calibrating the results of quick chemical tests by various methods.

These soils have been stored at the laboratory of the Division of Soil Chemistry and Physics, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Sets of small sub-samples of these soils will be supplied to persons engaged in research on the development or comparative study of soil testing methods.

Requests should be addressed to Dr. H. G. Byers, Division of Soil Chemistry and Physics, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.

EXTENSION SERVICE FILM STRIP

A CONTRACT for film strip production for the Extension Service of the U. S. Dept. of Agriculture has been awarded for the fiscal year 1939–40. Prices for film strip will range from 50 to 75 cents each, with the majority of the 325 series offered by the Department selling for 50 or 55 cents each. A price list of avaliable strips and instructions on how to purchase them may be obtained by writing to the Extension Service in Washington, D. C.

Film strips are available on such subjects as soil conservation, farm crops, dairying, farm animals, farm forestry, plant and animal diseases and pests, roads, farm economics, farm engineering, home economics, adult and junior extension work, and rural electrification. Lecture notes are provided with each film strip purchased, with the exception of those that are self-explanatory.

NEWS ITEMS

JERRY H. MOORE, cotton technologist for the North Carolina Agricultural Experiment Station, was awarded the degree of doctor of philosophy by Duke University last spring. Doctor Moore majored

in genetics and plant breeding and part of his graduate study was carried on at Cornell University.

Dr. Franklin S. Harris, President of Brigham Young University, has been given a leave of absence to accept a commission of the Government of Iran to reorganize the Department of Agriculture of that Government and to lay plans for the rehabilitation of the agriculture of the country. During Doctor Harris' absence, Dr. Christen Jensen, Dean of the Graduate School, will serve as Acting President of Brigham Young University.

Dr. D. W. Thorne, until recently Associate Professor of Soils at the Texas A. and M. College, has been appointed to a similar position at the Utah State Agricultural College and Experiment Station. In his new position, Doctor Thorne will divide his time about equally between teaching and research in soils.

Dr. Leonard H. Pollard has been appointed Assistant Professor of Vegetable Crops at the Utah State Agricultural College and Experiment Station where he will teach the work in vegetable crops and do research in vegetable crop production and genetics. Doctor Pollard was formerly associated with the University of California at Davis where he served as Associate in Vegetable Crops and where he recently completed work for the doctorate degree in genetics.

Dr. A. E. Brandt, Senior Statistical Analyst and also Acting Chief of the Division of Soil and Water Conservation Experiment Stations for the Soil Conservation Service in Washington, is spending the first summer session at the Utah State Agricultural College where he is teaching courses in statistics and in the design of experiments. Doctor Brandt is also conducting informal conferences with Experiment Station staff members in the design of experiments and in the analysis of experimental data.

Dr. R. D. Lewis whose major activities have recently been in extension and resident teaching at Ohio State University, has been appointed to a full time teaching-research position with the titles of Professor of Agronomy in the University and Associate in Agronomy in the Ohio Agricultural Experiment Station. In the absence of Doctor Salter, Chief of the Agronomy Department of the Experiment Station at Wooster and Chairman of the Department of Agronomy at Ohio State University, Doctor Lewis will serve as Vice-Chairman of the College Department. In addition to present teaching duties he will be responsible for the Department's program of instruction in crop genetics and breeding with major emphasis upon development in the graduate area. For the Experiment Station he will direct and supervise certain phases of the crops breeding program and will continue to give attention to problems dealing with the practical utilization of the output of crops breeding programs.

David F. Beard, for the past three years graduate fellow in agronomy and assistant secretary-treasurer of the Ohio Seed Improvement Association, has been appointed Extension Agronomist

to succeed Doctor Lewis. Mr. Beard has also been elected to replace him as Secretary-Treasurer of the Ohio Seed Improvement Association.

Dr. E. G. Bayfield, formerly Cereal Technologist, U. S. Dept. of Agriculture, in charge of the Federal Soft Wheat Laboratory, and Associate in Agronomy, Ohio Agricultural Experiment Station, has recently taken up his duties as Head of the Department of Milling Industry, Kansas State College, Manhattan, Kansas.

Dr. Olaf S. Aamodt, formerly head of the Department of Agronomy at the University of Wisconsin, has been named Principal Agronomist in charge of the Division of Forage Crops and Diseases of the U. S. Dept. of Agriculture to fill the position vacated by Dr. P. V. Cardon, recently named assistant chief of the Bureau of Plant Industry. In his new position Dr. Aamodt will direct all federal research on the production and improvement of forage plants throughout the United States and will have general supervision of the Northeastern Regional Pasture Laboratory at State College, Pa.

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MAIZE SEED CHARACTERS IN RELATION TO HYBRID VIGOR[1]

MORRIS E. PADDICK AND HOWARD B. SPRAGUE[2]

BECAUSE selected strains of hybrid corn are playing an increasingly important role in crop production, papers dealing with the maize kernel and its parts have been frequent. Some have been concerned with the effect of heterosis on the grain itself, others in explaining hybrid vigor through differences in embryo characteristics, such as size and amount of meristematic material. The study herein reported had as its purpose the prediction of high- or low-yielding ability for a strain through measurement of some specific kernel characters.

Kiesselbach and Cook (5)[3] in 1924 published observances on the increase of kernel weight through stimulation by foreign pollen. They ascribed such increases to changes in endosperm composition and to heterosis. Then later Kiesselbach (4) reported that the gain was a matter of kernel competition where hybrid kernels became heavier at the expense of adjoining inbred kernels. Ashby (1, 2), from a study of heterosis, concluded that hybrid vigor was due to a greater weight of the embryo which gave an advantage maintained throughout the grand period of growth. He proposed that growth rate be considered a simple dominant character. Sprague (6), however, could find no correlation between embryo size and heterosis, and found that hybrids grew relatively faster than either of the parents. His investigations indicated no difference in the growth rates of reciprocal crosses, although there were decided differences in embryo size. e therefore held to the theory of complementary action of dominant growth genes. As further evidence negative to Ashby's hypothesis, Bindless (3) reported the apparent lack of correlation between size of plumular meristem, or of the size of the cell nuclei contained therein, and hybrid vigor.

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[1]Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Agronomy. Received for publication May 17, 1939.

[2]Former research assistant, and Agronomist, respectively. The authors are indebted to Dr. W. E. Loomis, Iowa State College, Ames, Iowa, for helpful advice and criticism in the preparation of this report.

[3]Figures in parenthesis refer to "Literature Cited", p. 750.

MATERIAL AND METHODS

The seed material used in these studies was in part obtained from the New Jersey Experiment Station breeding stocks, but mostly from special crosses. In the latter case inbred lines characterized by white kernel endosperm were used as ear parents in crosses with lines carrying the factor for yellow endosperm. By using mixed pollen, one part of which was derived from the female parent plant, inbred as well as hybrid kernels were obtained on the same ear. Comparisons might thus be made between two germinal types, separation of the inbred from the hybrid seeds being possible through their color difference.

Kernel dissection was accomplished by soaking the grains in boiling water for approximately 5 minutes, removing the pericarp with a pair of tweezers, then splitting the kernel through the face and back, and finally digging out the germ with a dissecting needle. Kernel parts were dried at a temperature of 90° to 95° C for approximately 48 hours. To obtain weight means of desirable accuracy groups of 20 grains each were used. This number of kernels taken from each ear gave for the germ weight a mean with a probable error of less than 2%.

VARIABILITY IN KERNEL PARTS

Much variability was encountered in the weight of kernel parts, a portion of which could be ascribed to heredity effects, but a large amount of which was undoubtedly due to environment. Some appreciation of this problem may be gained by observing the data in Table 1. These illustrate the average weights of kernel parts as determined for the selfed line A55 and for the hybrids of which it was the ear parent. Forty adjoining kernels (20 inbred and 20 hybrid) were used for each of the hybrid-inbred kernel comparisons. So far as possible the grains for each comparison were obtained from a single ear.

Theoretically seeds which are genetically identical should show great uniformity. As the figures obtained for several lots of inbred kernels indicate, however, there were very decided differences from ear to ear and from season to season, not to mention from seed to seed.

Despite the disturbing effects of environment, differences which were due to heredity may be observed from the data of Table 1. In the percentage variability for the weight of germ, endosperm, and total seed, and especially for the endosperm-germ ratio, is this true. This may be confirmed by observing the coefficients of variability for the group of hybrids having A55 as maternal parent compared with the coefficients of the group of matched lots of A55 inbred kernels. The results are the same for both 1934 and 1935, although in the latter season poorer growing conditions caused the kernels to be smaller and less uniform.

For a summary, Table 2 may be referred to. Here nine hybrids are represented of which A55 was the ear parent and for eight of which B19 was the female parent. Likewise, nine groups of inbred A55 kernels and eight groups of inbred B19 kernels are also represented; each group having been formed from grains grown on the same ear and adjoining or close to those of the corresponding hybrid.

A basis was thus established for study of the various kernel parts and their interrelations in hybrids and inbreds. The object was to determine if any part, directly or indirectly, influenced the grain-

TABLE 1.—*Comparison of kernel parts of an inbred line of corn and hybrids from it.**

Strain	Dry weight in mgms, average of 20 grains									
	1934					1935				
	Pericarp	Endo-sperm	Germ	Total weight	Endosperm-germ ratio	Pericarp	Endo-sperm	Germ	Total weight	Endosperm-germ ratio
					Hybrids					
A55×A2	19.7	351.1	40.3	411.2	8.7	—	—	—	—	—
A55×A5	19.1	325.0	36.9	381.0	8.8	17.4	211.9	19.4	248.7	10.9
A55×A11	19.6	366.1	37.9	423.7	9.7	18.6	250.7	24.0	293.0	10.4
A55×A12	19.8	362.2	40.2	422.2	9.0	18.4	267.7	26.3	312.4	10.2
A55×A15	19.6	342.2	40.1	402.0	8.5	19.0	237.4	22.8	279.3	10.4
A55×A25	17.6	317.0	32.3	366.9	9.8	—	—	—	—	—
A55×A30	19.3	320.1	35.2	374.6	9.1	14.0	210.8	17.2	242.0	12.2
A55×A32	20.6	371.2	37.5	429.9	9.9	—	—	—	—	—
A55×A47	18.6	329.7	33.7	382.0	9.8	—	—	—	—	—
Mean...	19.3	342.8	37.1	399.3	9.25	17.5	235.5	22.0	275.1	10.8
S. D....	0.8	20.9	2.9	23.7	0.59	2.0	24.3	3.6	29.6	0.81
C. V., %	4	6	8	6	6	12	10	17	11	7.5
				A55 Inbred Kernels Paired With Hybrid						
A55 (A2)	17.0	242.1	26.6	285.7	9.1	—	—	—	—	—
A55 (A5)	16.5	256.2	29.4	302.2	8.7	16.8	157.3	16.4	190.5	9.6
A55 (A11)	19.1	260.2	28.5	307.0	9.1	15.4	162.0	18.2	195.7	8.9
A55 (A12)	18.0	255.7	29.4	303.2	8.7	14.9	165.8	17.8	198.5	9.3
A55 (A15)	17.3	255.7	29.7	302.7	8.6	17.5	172.4	17.6	207.5	9.7
A55 (A25)	15.3	222.2	25.9	263.4	8.6	—	—	—	—	—
A55 (A30)	18.7	239.2	28.8	286.7	8.3	12.5	134.1	14.7	161.4	9.1
A55 (A32)	18.5	256.0	29.1	303.7	8.8	—	—	—	—	—
A55 (A47)	17.6	264.1	30.1	311.8	8.8	—	—	—	—	—
Mean..	17.5	250.1	28.1	296.4	8.75	15.4	158.3	16.9	190.6	9.3
S. D....	1.2	13.2	1.4	15.1	0.25	1.9	14.6	1.4	17.5	0.33
C. V., %	7	5	5	5	3	12	9	9	9	4

*Determinations made on paired inbred and hybrid kernels from the same ear.
†Indicates the hybrid with which A55 kernels were paired as: A55 (A2) with A55×A2.

TABLE 2.—*Coefficients of variability for the means of the groups with each group composed of 20 kernels, 1934.*

No. of groups	Strain	Pericarp	Endo-sperm	Germ	Germ-endo-sperm ratio
9	A55 selfs	7	3	5	3
9	A55 hybrids	5	6	8	6
8	B19 selfs	18	14	9	8
8	B19 hybrids	16	16	11	12

or stover-yielding ability of a genetic line. The investigation logically resolved itself into two angles of attack, *viz*, the significance of absolute size as measured by weight and of relative size when compared to values obtained for the female inbred line—the ear parent Ashby's hypothesis of hybrid vigor in maize placed emphasis on the size of the embryo in the seed as an important factor, like the capital to which compound interest rate is to be applied. But even on casual observations this theory is subject to difficulties. Great uniformity of characters is the essence of a "pure" line, inbred or hybrid, and for all practical purposes the same may be said regarding reciprocal crosses However, the individual kernels of a specific line may vary greatly in size, depending on their position on the ear, the particular maternal plant, and the seasonal environment. Even more marked may be the difference in size between the kernels of reciprocal crosses

In view of the previously noted variability in average germ size between seed sample groups of the same line, it was considered desirable to investigate the correlation of germ weight with kernel weight. Let one assume germ size to have important direct influences on the future possibilities of the plant, such as grain and stover yields. Then observed uniformity of mature plants should follow from size uniformity of seed embryos themselves regardless of the total kernel weight. To test this supposition kernels of two strains of corn, one an open-pollinated variety, Lancaster Surecrop, and another a double cross (B42×A64)×(A30×A47), were sorted into air-dry weight groups 20 mgms apart. Kernel dissections were made and the endosperm and germ weights for each determined. The size relationships between the kernel parts are graphically shown in Fig. 1. There is no doubt that the germ tends to constitute a definite proportion of the total kernel weight, regardless of the seed size.

However, it must be admitted that for any given line the majority of the kernels will not deviate far from their mean weight, and thus the effects of extreme kernel size will not be apparent in the field. Since plat test yields are the averages of many plants in which the variability of the individual is lost, there is really no secure basis for assuming that embryo size does not have its effect. The writers know of no experiment designed especially to determine the relationship between embryo size and plant yield.

A more tangible means of ascertaining embryo size effect is through the comparison of reciprocal crosses. For all practical purposes the members of such a pair are genetically identical, and it is generally

assumed there is little difference at maturity. Any significant difference between the kernel embryo size of the two crosses would therefore discredit this seed part of any important influence on plant growth.

The data of Sprague (6) induce this conclusion. In one instance he was able to vary embryo size in a line through the harvesting of seed at various stages of maturity, but found no significant differences in plant growth rate Furthermore, he checked the growth rate of plants of reciprocal crosses where there was a significant difference in average embryo size, and again found no correlation between embryo weight and growth rate.

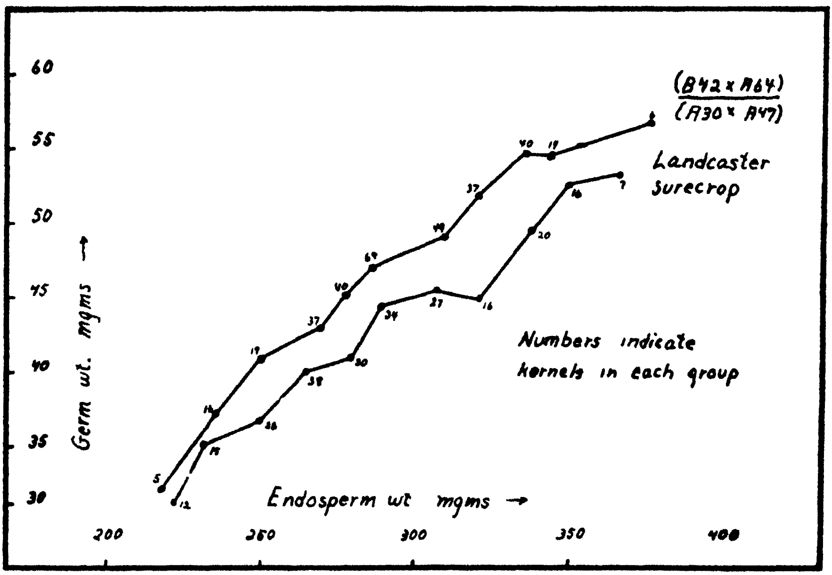

FIG 1 - Dry weight relation of germ to endosperm in kernels of the same strain.

In Table 3 will be found data on the kernel part weights for inbred lines and their reciprocal crosses, of which A55 is one parent. Of principal interest and significance, in accord with the foregoing conclusions, will be noted the marked variation in germ weight between the members of a reciprocal cross, although the genotype remains identical.

STIMULATION OF EMBRYO AND PLANT YIELD

The possibility of a direct relationship between embryo size and plant growth is not favored by the preceding data and by the data of others. Environmental conditions, especially the nutrition of the developing seed, have a highly significant role in determining the size of the kernel and its parts. The corn germ may perhaps best be considered as a transition stage in the growth of the plant, a necessary

TABLE 3.—*Seed part weights of reciprocal crosses and their parents, averages of 20 kernels.*

Strain	Pericarp, mgms	Endosperm, mgms	Germ, mgms	Percentage difference*	Endosperm-germ ratio
A55 selfed	17.5	250.1	28.1		8.75
A55×A2	19.7	351.1	40.3		8.7
A2×A55	5.2	123.5	15.2	90.6	8.1
A2 selfed	9.2	225.1	30.6		7.3
A55×A5	19.1	325.0	36.9		8.8
A5×A55	12.8	184.8	21.8	51.6	8.5
A5 selfed	21.4	276.1	31.9		8.6
A55×A9	18.0	267.2	30.8	23.2	8.7
A9×A55	9.8	180.1	24.4		7.4
A9 selfed	11.5	186.2	25.7		7.2
A55×A11	19.6	366.1	37.9	35.8	9.7
A11×A55	15.3	229.7	26.4		8.7
A11 selfed	17.6	227.0	24.4		9.3
A55×A12	19.8	362.2	40.2	13.8	9.0
A12×A55	13.5	245.9	35.0		7.0
A12 selfed	13.6	182.8	36.0		6.6
A55×A15	19.6	342.2	40.1	25.6	8.5
A15×A55	12.7	231.5	31.0		7.5
A15 selfed	12.6	192.9	28.1		6.5
A55×A25	17.6	317.0	32.3	32.3	9.8
A25×A55	14.0	208.0	23.3		8.9
A25 selfed	14.3	197.8	32.2		6.1
A55×A30	19.3	320.1	35.2	8.3	9.1
A30×A55	25.5	301.5	32.4		9.3
A30 selfed	23.7	244.9	24.7		9.9
A55×A32	20.6	371.2	37.5	36.3	9.9
A32×A55	10.7	237.0	26.0		9.1
A32 selfed	12.0	240.2	24.1		10.0
A55×A47	18.6	329.7	33.7	10.9	9.8
A47×A55	14.9	224.6	30.2		7.4
A47 selfed	13.1	194.2	26.6		7.3
Lancaster Surecrop	23.6	281.5	41.0		6.9

*Germ weight difference between reciprocals as % of their average.

suspension of activities in the change from one environment (on the ear) to another (in the soil).

It is to be remembered, however, that the hybrid or inbred plant comes into being with the fusion of the parental gametes to form a zygote. Hybrid vigor then is to be expected as much in the development of the embryo as in the plant following germination. Growing side by side in nearly identical environment (on the parental ear), hybrid kernels with their 2n germ and 3n endosperm should best

their inbred relatives in the struggle for nutriment as do plants in the field

There is then to be considered the significance of correlation between the stimulatory effect of cross fertilization on the corn kernel embryo and the potentialities of the hybrid plant produced By stimulatory effect is meant the increase in germ and endosperm weight of hybrid kernels over inbred kernels borne on the same ear, as illustrated in Table 4

TABLE 4 *Weights of hybrid kernel parts in percentages of the maternal inbreds when grown on the same ear with groups of 20 kernels each 1934*

No of groups	Strain	Pericarp %	Endosperm %	Germ, %
9	A55 hybrids	110 4 ±1 7	137 1 ±2 6	129 7 ±3 7
3	B8 hybrids	100 6 ±1 4	106 9 ±4 4	108 0 ±1 4
4	B16 hybrids	100 5 ±5 0	118 2 ±3 8	120 2 ±5 0
3	B18 hybrids	108 6 ±3 0	117 6 ±9 3	142 5 ±21 8
8	B19 hybrids	113 5 ±10 1	140 7 ±7 4	149 0 ±4 0

To test the possibility of using degree of embryo stimulation as an indicator of strain yield in stover and grain, a correlation coefficient was determined The percentage germ weight increase of hybrid kernels over inbred kernels developed on the same ear was taken as one variable Grain and stover yields as percentage of a check variety were used as the other variables A number of such inbred-hybrid paired groups were used, representing crosses made on five inbred ear parent lines The results are as follows

Correlation	Year and pairs correlated 1934 (24)	1935 (22)
Germ increase with grain yield	42	36
Germ increase with stover yield	- 12	12
r value at 5% level of significance	404	42

Such a comparison as this is theoretically justified on the grounds that in all likelihood many of the plant characteristics which enter into the phenomena known as hybrid vigor are of an intangible and unmeasurable nature Rates of reaction, sequence of processes, and balance of material distribution are perhaps all decisive factors in determining the adaptations and potentialities of the plant Measurements of an indirect nature must be made through direct comparison of the total plants themselves, judging one in terms of another

Comparing the kernel development of inbred and hybrid seed on the same ear is a measurement of this nature at a very early stage.

Admittedly there is a handicap in having to use the same maternal parent in all hybrids to be compared and thus not being able to compare unrelated lines. However, this method does offer a means for studying lines during their earliest period of growth, from zygote to embryo, a stage in which little has as yet been done.

SUMMARY

The pollen parent seems to be able to exert some influence on the weight of both corn kernel germ and endosperm and the ratio between the two. The general effect of outbreeding on the kernel is size stimulation.

Germ size in reciprocal hybrid kernels may vary greatly despite uniformity of mature plants, tending to substantiate Sprague's views on Ashby's hypothesis that embryo size is not a significant factor in the induction of hybrid vigor.

The ratio of endosperm-germ weight within a specific line remains relatively constant regardless of kernel size.

There seems to be no correlation between weight increase of hybrid kernel germ over that of the ear parent, when borne on the same ear, and forage-yielding ability. There seems to be a barely significant correlation (r equals approx. .39) between this germ weight increase and grain-yielding ability of hybrid strains.

The technic of producing hybrid kernels on the same ear as their maternal inbreds is suggested as a means of studying the development of hybrids in the period between the formation of the zygote and the maturity of the embryo.

LITERATURE CITED

1. Ashby, Eric. Studies in the inheritance of physiological characters: I. A physiological investigation of the nature of hybrid vigor in maize. Ann. Bot., 44:457–469. 1930.
2. ————. Studies in the inheritance of physiological characters: II. Further experiments upon the basis of hybrid vigor and upon the inheritance of efficiency index and respiration rate in maize. Ann. Bot. 46:1007-1032. 1932.
3. Bindless, Elizabeth A. Nuclear size in plumular meristem of inbred and hybred maize. Amer. Jour. Bot., 25:738–743. 1938.
4. Kiesselbach, T. A. The immediate effect of gametic relationship and of parental type upon the kernel weight of corn. Nebr. Agr. Exp. Sta. Res. Bul. 33. 1926.
5. ———— and Cook, G. C. The relative effects of foreign pollen upon the kernel weight of commercial varieties and selfed strains of corn. Jour. Amer. Soc. Agron., 16:30–36. 1924.
6. Sprague, G. F. Hybrid vigor and growth rates in a maize cross and its reciprocal. Jour. Agr. Res., 53:819–830. 1936.

BIOCHEMICAL APPROACH TO GRASS PROBLEMS[1]

A. G. NORMAN[2]

IN its biochemical aspects, as in others, the pasture problem is a peculiarly complex one. Most studies in crop production and crop quality are concerned with the yield and composition of a certain part of the plant, grain or root, at maturity, the plant having been allowed to develop normally from the seedling stage to ripeness. High yields of mature material are not necessarily what we require of grassland, but instead a steady yield of immature material that shall be of high digestibility and nutritive value. The growth of the herbage may be checked by grazing or accelerated by fertilizer applications, and at the same time the botanical composition of the pasture may be radically altered. Therefore one is not dealing with a simple cycle of growth changes, but a sequence of superimposed effects not necessarily in phase. Pasture work in this respect bears to ordinary crop production studies the same sort of relationship that soil population studies bear to conventional pure cultural microbiology. It is often difficult to plan pasture experiments in which the chief factors are under control without laying the whole experiment open to the criticism of being highly artificial. To give only one example, there is the thorny point as to whether mowing as frequently practiced in experimental work is really equivalent to grazing by animals

The purpose of a pasture is to produce feed that is of high quality. The aim of the biochemist is to be able to determine analytically the composition of the herbage in order that its value to the animal may be assessed and the consequences of particular management practices determined. The animal requires primarily a source of energy and secondarily certain specific and essential nutrients for body maintenance and growth. In the latter division fall the proteins contributing vital amino acids, the mineral constituents, and vitamins. There are fashions in research as in other fields, and much of the biochemical work on forage crops in recent years has been concerned quantitatively with minor constituents, such as the mineral constituents, carotene, and the vitamins, and lately also with essential amino acids. There seems to be, however, a regrettable tendency in considering the quality of grass to look chiefly at the nitrogen content and to imply that young grass is so much better than mature hay simply because of the higher content of protein it contains. Beasts do not live by protein alone, and even in the best grass the protein is a relatively small part of the whole. There appears then to be a real need for a further study of the energy-supplying constituents, which together comprise by far the greatest proportion of feeds, an examination of their relative availabilities, the prediction of their digestibility, and the study of management practices that will maintain a profitable compromise between yield and quality. This means that it

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[2]Professor of Soils.

will be necessary first to break down some of the complex pasture problems into simpler units which may separately appear not to be very practical, but which taken together should give what is wanted. The changing composition of the plant with age, the effect of fertilizers, and management, all ought to be determined independently first.

In the general question of digestibility there is no matter more important than the nature of those plant constituents, largely carbohydrate in nature, that supply the animal with energy. The field has somehow been neglected, perhaps because the necessary analytical methods have not been available. The main difficulty is that, in general, the properties of these substances are not clearly and sharply defined, so that the convenient solution and reprecipitation methods of inorganic chemistry are not applicable and recourse has to be had to procedures that aim at excluding other constituents and leave the required substance as a residue. The conventional system of analysis used for forage crops divides the carbohydrates quite empirically into two groups, "crude fibre" and "nitrogen-free extractives", the latter being obtained only by difference from 100 when other analyses have been totaled up.

Crude fibre is commonly pictured as being the fibrous, poorly digested, relatively unavailable part of the feed and the "N-free extractives" the easily digestible carbohydrates. This belief is firmly held and often expressed. Carefully conducted digestibility trials, however, not infrequently show (2)[3] the coefficient of digestibility of the "crude fibre" to equal that of the "nitrogen-free extract." Further, a consideration of the properties of the structural constituents that are presumed to be poorly digested and to be represented in the crude fibre fraction shows that they are likely to be very inadequately recovered in it. The chief structural constituents are cellulose, the polyuronide hemicelluloses, and lignin, but analyses of the crude fibre fraction from a number of forage crops have shown that it usually consists only of a portion of the cellulose, generally 60 to 80%, mixed with a small and very variable amount of lignin (4).

The proportions of the cellulose and lignin that are recovered vary so much even on the same type of material that the crude fibre fraction is not a reliable index of developmental changes in composition. It would be an important advance if the determination of the crude fibre fraction and its use in expressing composition were abandoned as inadequate, unreliable, and misleading. The most serious criticism of the present system of analyses used for grasses and forage crops is that there is included no measure of the lignin content. The concensus of opinion is that lignin is almost wholly unavailable to herbivorous animals, though in point of fact the data available on this point are extremely scanty. Experiments in which the fate of isolated lignin added to the diet is determined (3, 7), are not conclusive since the biological availability of lignin is known to be affected by the processes of isolation (5).

However, Crampton and Maynard (2) recently showed that 98% of the lignin in mixed pasture herbage clipped at different dates

[3]Figures in parenthesis refer to "Literature Cited", p. 760.

through the season could be recovered in the faeces of rabbits and approximately the same amount in that of a steer. Cellulose, on the other hand, though not directly digested by the animal is made available as a result of bacterial action in the rumen and intestine, and pure cellulose was long ago calculated to have a high "starch equivalent," which is to say that its energy is nearly as available as that of starch. The cell walls of young tissues are primarily cellulosic but as the tissue develops and the wall thickens lignin and hemicelluloses are deposited along with newly formed cellulose, encrusting and infiltering the cellulosic fabric to give inter-penetrating systems. The presence of lignin retards and prevents the bacterial degradation of the cellulose, probably largely through mechanical action. Deposition of lignin is more or less progressive with age and in general digestibility diminishes with age, but there comes a critical point beyond which cellulose availability is relatively small The effect of the presence of lignin is not only to reduce the utilization of the cellulose but unless the feed is ground very fine, access of digestive juices to cell contents such as protein and more available carbohydrate is also hindered. As a result it is probably true to say that the degree of lignification of any normal forage crop affects its digestibility more directly than any other factor Exactly how the degree of lignification may best be expressed has not been determined. The ratio of lignin content to cellulose content may prove to be more adequate than simple lignin percentage. This has not yet been tested by digestibility studies but is the logical probability from the arguments above.

The present system of analyses includes no measure of the lignin except insofar as the deposition of lignin is parelleled by the deposition of cellulose, part of which is represented in the crude fibre fraction. Even worse, the lignin is in fact included as an available constituent in the "nitrogen-free extractives" figure obtained by difference. This lengthy preamble is the case for the direct determination of cellulose and lignin as a minimum requirement in studies of pasture herbage composition In addition it would be desirable that an attempt should be made to separate the other major carbohydrates, both structural and reserve, in order that the percentage of material unaccounted for shall be as small as possible, and not a composite of errors in method and technic as at present.

As illustrating the use of these newer analytical procedures and the breakdown of the pasture problem into the equivalent of pure cultural studies, the following experiments on the changing composition of grasses with age and fertilizer treatment might be quoted. These experiments were carried out at the Rothamsted Experiment Station in the seasons of 1935, 1936, and 1937 and the grasses concerned were rye grass (*Lolium italicium*), an annual variety known as Western wolths, and cocksfoot[4] (*Dactylis glomerata*). These were chosen as being some way apart on the scale of palatability. In the first season it was found that the cold water extract of immature rye grass was astonishingly high, approaching 50% in young samples. A portion of this was nitrogenous, of course, but the remainder to a considerable extent was found to consist of a fructose polysaccharide that may be

[4]Known in the United States as orchard grass.

described as fructosan or levan. The presence of fructose polysaccharides in members of the Gramineae has been reported a number of times, under such names as graminin, or sinistrin, but the amounts present have been regarded as small. In young rye grass at one stage more than one-third of the dry weight was fructosan, the percentage of which later decreased rapidly as maturity approached (Table 1).

TABLE 1.—*Fructosan in ryegrass, 1935.*

Sample No.	Date cut	Fructosan, %*
1	April 26	28.2
2	May 10	26.6
3	May 24	37.5
4	June 7	25.3
5	June 21	18.9

*Expressed as fructose after hydrolysis.

It is evident that this polysaccharide must be an important temporary carbohydrate reserve and must not be overlooked in digestibility studies, since at the time of peak content, it is quantitatively the major constituent of the grass. A similar fructosan has been found in young wheat and barley plants, the amount also falling rapidly as the ears form (1). The unexpected observation of the presence of this polysaccharide as a major constituent of young rye grass brings out another point that should be stressed, namely, that little is really known of the carbohydrate metabolism of grasses. Indications of the presence of a water-soluble glucose polysaccharide in comparatively small amounts were also obtained.

To obtain a detailed picture of the developmental changes in rye grass, composite weekly samples were taken from six plats each 1 square yard in size from early May to the end of July. This number of samples was insufficient for accurate yield data and in later experiments the number of plat samples was increased to eight. The grass was cut with shears, heated briefly at 100° C, and finally dried at about 35°. Soil nitrogen determinations were also made at each time of sampling. A selection of the analyses are given in Table 2, the full data being recorded by Norman and Richardson (6).

The nitrogen changes, here expressed for convenience as crude protein a practice that is probably almost as undesirable as the determination of crude fibre, were not unusual. The soil analyses showed that at all times there was a sufficiency of available nitrogen. The cellulose content appeared to increase steadily from 26% to 46%, though there was an indication in mid-June of rather more rapid deposition just about the time the heads were ripening. There was no increase in dry weight after the sixth or seventh sampling period, but nevertheless the cellulose content continued to rise, implying its formation from some other constituent (Fig. 1).

The lignin figures had a similar trend. Lignification is sometimes described as being a sudden and dramatic process ordinarily occurring when growth slackens toward maturity and accelerated particularly by drought or other unfavorable conditions. This hardly appears to be the case in grass, for the deposition of lignin took place steadily

TABLE 2.—*Yield and composition of rye grass (Western Wolths) expressed as percentage of oven-dry material.*

Sample No.	Date cut	Grams per sq. yd.	Crude protein, %	Cellulose, %	Lignin, %	Fructosan, %	Cellulose / Lignin
1	May 12	23	11.8	26.1	3.6	25.6	7.3
2	May 19	54	9.3	26.4	4.7	26.9	5 6
3	May 26	64	9.1	28.9	5.2	30.1	5.5
4	June 2	93	7.8	32.0	5 9	28.1	5.4
5	June 9	126	6.9	32.2	7.0	26.8	4 6
6	June 19	166	6.4	33.8	8.7	21 3	3.9
7	June 22	150	6.0	40.4	9 0	17.0	4.5
Hay*	June 22–29	—	5 6	43.2	10.4	11.8	4.2
8	June 30	161	5.4	38.3	9.1	14.7	4.2
9	July 7	161	4 7	39.9	9.6	12 6	4.2
10	July 14	165	4 7	43.2	10.5	7.0	4.1
11	July 20	151	4.2	47.1	11.2	5 7	4.2
12	July 26	126	5.0	46.2	11 1	3.2	4.2
13	Sept 21	- -	6 7	48.8	16 4	0.4	3.0

*This represents herbage cut on June 22 and allowed to dry in the field until June 29

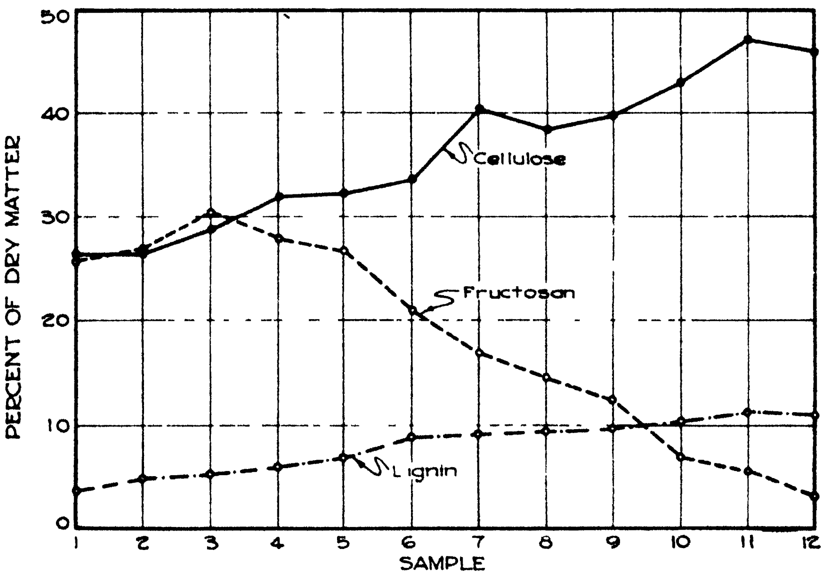

FIG. 1.—Changing composition of rye grass with age.

over the whole growing period and the ratio of cellulose to lignin narrowed gradually to about 4. From what is known of the large decrease in digestibility of grass that follows the formation of the seed, a relatively small change in lignin content must vitally affect availability, unless some other factors are also concerned. This may be the case as is demonstrated by the figures for fructosan content. High in the young samples it falls rapidly with maturity. The peak content appears to occur just about the time of full emergence of the head, but

because the dry weight may still be increasing the maximum on a unit area basis falls later. In this experiment the fructosan per acre attained its maximum at the time of the sixth sample when it amounted to nearly 400 pounds per acre (Fig. 2).

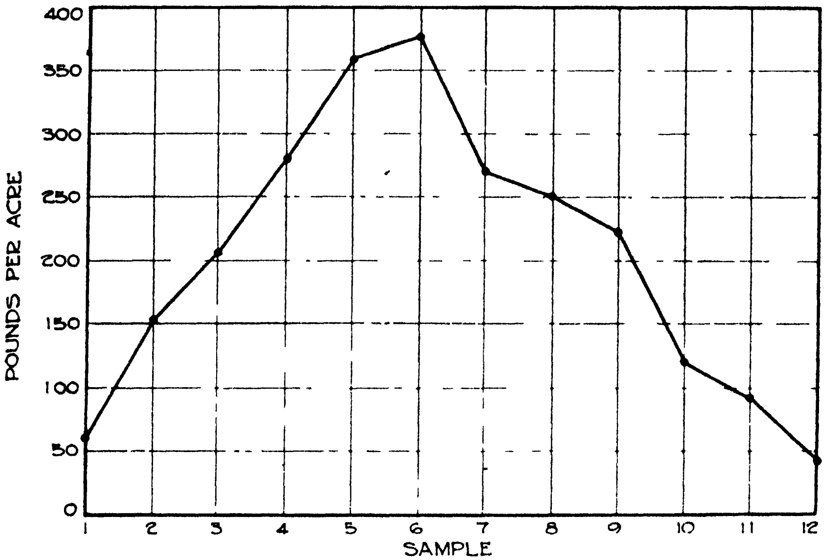

FIG. 2. - Yield of fructosan in rye grass.

Fructosan is extremely soluble and very easily hydrolysed. Its enzymic breakdown has been little studied, but either directly or by bacterial action this carbohydrate is probably of great nutritional importance. Its distribution within the plant has been followed to some extent. Synthesis no doubt occurs in the leaves, but the chief place of storage is the stem and particularly the first internode above ground level which contained as much as 42.8% (Table 3).

TABLE 3. - *Distribution of fructosan in ryegrass, June 2, 1936.*

Plant parts	Fructosan, %	Dry weight, % of aerial parts
Leaves	24.4	25.4
Stem	35.4	51.5
Heads	17.3	23.2
Root	25.0	—
1st internode	42.8	—
2nd internode	34.1	—
Aerial parts	28.1	—

The occurrence of this polysaccharide as a temporary reserve raises a number of physiological questions which cannot be answered at present. There is a strong probability that much of the fructosan is used subsequently for the production of structural constituents par-

ticularly cellulose, because although no increase in dry weight occurred after the time of the sixth or seventh sample, there was thereafter a steady rise in structural constituents and a comparable fall in fructosan (Fig. 3). These analyses demonstrate that there is a

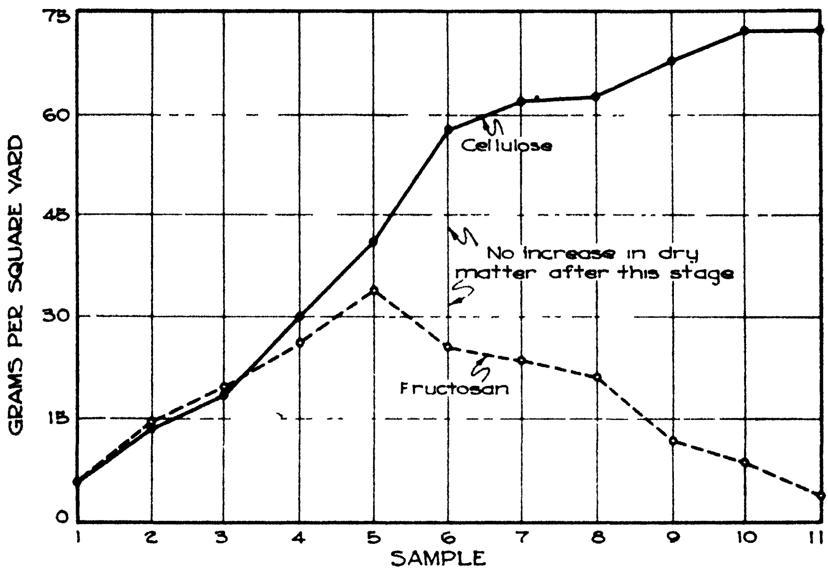

FIG. 3. - Changes in cellulose and frutosan in rye grass expressed on an area basis.

greater difference between young grass and mature grass than a lower lignin content and a higher protein content, and that transformations in the type of carbohydrate present may also be an important factor in affecting availability.

Certain of the plats were recut later in the season in order to obtain information as to the composition of the second growth and, while the experiments were incomplete, there was a strong indication that second growth grass contains a higher percentage of structural constituents and a lower percentage of fructosan than first growth when compared on a basis of equal protein content (Table 4) The data are insufficient to permit of any definite statement, and this question which is of great practical significance calls for further examination.

The cocksfoot analyses (Table 5) are perhaps less interesting than those of rye grass.[6] Cocksfoot evidently contains a considerably higher percentage of structural constituents, even at the young stage. Seven per cent was the lowest lignin content recorded, with an increase up to 12% or more on mature samples. Fructosan was present but in smaller amounts, the maximum being 11% on the first cut taken. The fructosan content declined to maturity but was by no means negligible even in the oldest samples. This is different from its

[6]The full data are to be found in a forthcoming paper in the Biochemical Journal.

TABLE 4.—*Comparison of first and second growth rye grass, 1936, composition expressed as percentage of oven-dry material.*

Sample No.	Date cut	Grams per sq. yd.	Crude protein, %	Cellulose, %	Lignin, %	Fructosan, %
1	May 12	23	11.8	26.1	3.6	25.6
1-1	June 15	51	10.4	38.4	8.2	14.2
2	May 19	54	9.3	26.4	4.7	26.9
2-1	June 29	80	7.5	37.9	10.1	12.2
3	May 26	64	9.1	28.9	5.2	30.1
3-1	July 14	112	7.1	33.2	9.2	8.9
4	June 2	93	7.8	32.0	5.9	28.1
4-1	July 27	109	5.4	42.9	11 5	5.5

behavior in rye grass. Additions of nitrogen were made to a part of the area in order to determine the effect of prolonging vegetative growth. The yield of dry matter was much increased and the nitrogen content enhanced, as would be expected. Little effect was produced in the amounts of cellulose and lignin, though on some samples the cellulose content seemed slightly reduced and the lignin content increased as a result of the applications The ratio of cellulose to lignin, which might perhaps be considered as some measure of the degree of lignification was curiously enough almost consistently narrower in the plats that had received nitrogen. In all cases, however, the fructosan was reduced, this being in accord with observations on the effect of nitrogen on this constituent in barley (1, 8).

TABLE 5.—*Yield and composition of Cocksfoot, 1937, composition expressed as percentage of oven-dry material.*

Sample No.*	Date cut	Grams per sq. yd.	Crude protein, %	Cellulose, %	Lignin, %	Fructosan, %	Cellulose / Lignin
1-N	May 10	90	12 3	38.5	7.9	11.3	4.9
2-O	May 18	130	11.0	42.4	7.1	11.1	6.0
2-N	May 18	124	15.4	41 3	7 0	9.4	5.9
3-O	May 24	166	9.9	44.4	8.6	8.7	5.2
3-N	May 24	186	12.1	46.0	8.7	5.8	5.3
4-O	May 31	196	7.5	46.8	10.2	8.3	4.6
4-N	May 31	277	12.3	44.7	11.1	4.8	4.0
5-O	June 7	257	7.0	45.8	11.1	7.5	4.1
5-N	June 7	377	10.3	45.8	12.0	5.7	3.8
6-O	June 14	284	5.3	48.9	11.1	6.9	4.4
6-N	June 14	413	10.6	46.2	12.4	5.0	3.7
7-O	June 21	335	5.4	48.6	11.9	7.8	4.1
7-N	June 21	456	9.1	45.6	12.4	7.3	3.7
8-O	June 28	314	5.4	46.4	12.1	9.7	3.8
8-N	June 28	260	7.9	44.3	11.8	8.2	3.8

*Samples with suffix N came from plats receiving nitrogenous fertilizer, those with O from untreated plats. Applications of nitrogen were made as follows: On May 10, ammonium sulfate equivalent to 46 lbs. N per acre; on May 24 and June 7, ammonium sulfate equivalent to 23 lbs. N per acre.

The second growth was taken from all plats after an interval of four weeks, no further additions of nitrogen being made (Table 6). As in the first growth the effect of nitrogen seemed to be manifest in a reduction in fructosan content and an increase in lignin. The fructosan

was in all cases relatively low, but unlike rye grass it cannot be said of the second growth that the percentage content of structural constituents is higher than the first growth when material of approximately equal nitrogen content is compared.

TABLE 6.—*Yield and composition of Cocksfoot (second cut 4 weeks growth) expressed as percentage of oven-dry sample.*

Sample No.*	Date cut	Grams per sq. yd.	Crude protein, %	Cellulose, %	Lignin, %	Fructosan, %
1-O1	June 7	55	12.0	40.1	8.6	6.7
1-N1	June 7	137	19.3	40.8	9.0	3.8
2-O1	June 14	49	13.5	43.5	8.8	3.5
2-N1	June 14	119	17.9	41.0	10.0	2.8
3-O1	June 21	41	12.2	42.1	8.2	6.1
3-N1	June 21	122	14.3	40.8	10.0	5.0
4-O1	June 28	35	11.7	40.5	8.9	6.7
4-N1	June 28	106	14.1	39.8	9.1	6.0
5-O1	July 5	21	12.0	42.7	8.3	5.1
5-N1	July 5	68	14.0	40.8	8.4	5.4
6-O1	July 13	20	12.2	46.8	8.5	5.6
6-N1	July 13	61	13.6	44.1	9.9	5.7
7-O1	July 20	23	10.9	44.8	9.5	3.5
7-N1	July 20	45	12.3	44.4	9.1	4.4
8-O1	July 27	12	10.1	44.2	9.9	2.6
8-N1	July 27	24	13.5	43.8	9.8	3.7

*Samples with suffix N came from plats which originally received nitrogenous fertilizer

These data have been presented not so much to prove certain theories or to indicate certain changes in grasses, as to demonstrate the possibilities of this approach to studies of composition. In themselves they are insufficient and only a beginning of what will have to be done extensively if a detailed picture is to be obtained of the variation in composition of herbage with age, with fertilizer treatment, and with management. Arising out of the data presented, the following points seem to call for attention and to be capable of solution by an extension of the direct methods of determination just described:

First, what is the nature of the primary and secondary carbohydrate metabolism of grasses? Is fructosan a major temporary reserve only in rye grass, or is it to be found generally in many species? What relationship, if any, is there between fructosan formation and storage and the rapidity of new growth following cutting or grazing? Are there other reserve carbohydrates as yet unidentified?

Second, what is the influence of lignification or lignin deposition on the digestibility of herbage? Are the advantages of feeding young grass so exclusively confined to the higher protein content and greater digestibility of the cellulose as has been supposed, or may not the replacement of much soluble polysaccharide by insoluble structural constituents be also concerned?

Third, what is the nature of the hemicelluloses of grasses? How may they be determined, and what role, if any, do they play in affecting the value of the herbage? Can they act as reserves, as has sometimes been asserted, or should they properly be regarded as structural constituents and consequently out of circulation so far as renewal of

growth after cutting is concerned? Because of limits of time this group has not been discussed, but it should perhaps be stated that in all the samples mentioned the hemicelluloses were probably quantitatively more important than the lignin.

This list of questions could be considerably extended, particularly if the nitrogenous constituents are also included. Most of the questions are quite fundamental to a fuller understanding of grasses and the proper management of grassland. Their solution depends on the further development of biochemical methods in this field and the abandonment of empirical procedures as research tools.

LITERATURE CITED

1. ARCHBOLD, H. K. Physiological studies in plant nutrition. VII. The role of fructosans in the carbohydrate metabolism of the barley plant. Ann. Bot. (N.S.), 2:403-436. 1938.
2. CRAMPTON, E. W., and MAYNARD, L. A. The relation of cellulose and lignin content to the nutritive value of animal feeds. Jour. Nutrition, 15:383-395. 1938.
3. CSONKA, F. A., PHILLIPS, M., and JONES, D. B. Studies on lignin metabolism. Jour. Biol. Chem., 85:65-75. 1929.
4. NORMAN, A. G. The composition of crude fibre. Jour. Agr. Sci., 25:529-540. 1935.
5. ————. The biological decomposition of lignin. Sci. Prog. No. 119:442-456. 1936.
6. ———— and RICHARDSON, H. L. The composition of forage crops. II. Rye grass (Western wolths). Changes in herbage and soil during growth. Biochem. Jour., 31:1556-1566. 1937.
7. PHILLIPS, M., WIEHE, H. D., JONES, D. B., and CSONKA, F. A. The demethoxylation of lignin in the animal body. Proc. Soc. Exp. Biol. and Med., 26:320-321. 1929.
8. RUSSELL, R. S. The effect of mineral nutrition on the carbohydrate metabolism of barley. Ph.D. Thesis, University of London. 1937.

THE INFLUENCE OF EXCHANGEABLE IONS AND NEUTRAL SALTS ON THE pH OF SOILS[1]

M. PUFFELES[2]

Sörensen and Palitzsch (11),[3] in their investigations on the pH of salt solutions, came to the conclusion that two solutions containing some dissolved inorganic material show the same coloration when tested with an indicator if their pH's are similar. If the concentrations of the two solutions vary, however, the indicator does not show the same color. Thus, they demonstrated the lowering of the pH on the addition of some salt to one of the solutions having similar concentrations and naturally came to the conclusion that the addition of such a salt, whether neutral or not, increases the pH or its activity, which, in its turn, results in a lower reading. Later, they (12) also demonstrated that the determinations of the pH in a neutral salt solution do not agree when measured by means of electrometric and colorimetric systems Their determinations gave a mean difference of 0.05 to 0.07 between the two methods. They also found that in a 3.5% neutral salt solution the pH is diminished by 0.24.

McBain and Colman (8) found that the rate of inversion caused by 0.25 N/HCl was increased by 8.47% on the addition of 0.25 N/KCl solution. Michaelis and Rona (9) have demonstrated that variations of color in a solution do not depend solely on the pH, but are also affected by the concentration of neutral salt in the solution. They think that changes in the color of the solution are due to the effect of the neutral salt on the dissociation constant of the indicator. They also found that by adding a neutral salt, such as NaCl, to a solution of acetic acid, the dissociation constant of the acid is increased. The influence of a neutral salt on lowering the pH of a given soil is now a well-known fact in the case of humid soils. Such lowering also serves as an index of the unsaturation of the zeolite-complex and of the amount of lime which should be added to the soil. In the case of arid soils very few investigators have observed a diminishing pH value following the addition of a neutral salt. Arrhenius (2) has shown that the presence of salts in certain Egyptian soils has prevented the formation of black alkali. He also points out that the addition of a neutral salt to an alkaline clay (considered an absorptive, saturated clay) produces a greater lowering of the pH than its addition to unsaturated soils and attributes this to the fact that the addition of a neutral salt activates the hydrogen ions and suppresses the OH group. As to the degree of activation exercised by the nonmetallic ions on the hydrogen-ion concentration in the soil, Arrhenius found that Cl is more active than NO_3, while nitrate is more active

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[1]Contribution from the Central Laboratories, Dept. of Health, Government of Palestine, Jerusalem. Received for publication May 16, 1939.

[2]Chemist. The author wishes to express his thanks to G. W. Baker for his advice and corrections on this paper and to S. Adler for her assistance in the analytical work reported here.

[3]Figures in parenthesis refer to "Literature Cited", p. 766.

than SO_4. As far as the cations are concerned the strongest is Fe,[4] then come Ca, Mg, K, NH_4, and lastly Na arranged in decreasing strength.

The writer (10) has observed in an investigation of many Jericho soils that the addition of a neutral salt decreases the value of the pH.

Aarnio (1), in his study of the influence of absorbed ions on soil reaction, has found that the pH of clay saturated with a monovalent or bivalent cation decreases with an increase in atomic weight, and is lower in the case of the bivalent cation clays as compared with the monovalent type.

Wiegner, et al. (13, 14, 15) and Gallay (4) measured the viscosity and the ultramicroscopic coagulation of the suspension of different clay cations. In doing this they discovered that the position of these cations in the periodic system was interrelated with the water absorptive and coagulation properties of the clay which they saturate. It was found that, as a rule, the increase in the atomic weight of monovalent and bivalent cations fixed by the clay soils brings about a lessening of the water-absorbing power of the clay cation, increasing at the same time its capacity for coagulation

It seems reasonable to suggest, therefore, that the absorbed cation might have a specific influence on the stability of the complex, as well as on the pH, and that a neutral salt would also influence the different exchangeable cations.

METHODS

Three different types of soil, *viz.*, a heavy, a light, and a calcareous soil, were chosen for the experiment with a view to discover the influence of neutral salts on the pH in the solutions.

Colorimetric measurements were used of water extracts of the soils rendered as colourless as possible. Since filtration affects the reaction of the extract, the latter were prepared by the centrifuging. In cases where the suspension was not clear, it was clarified with barium sulfate, using Kuhn's method (7). The actual measurements were taken with the Hellige comparator. Pyrex glass was used for the determinations of colors in order to avoid errors consequent on the solubility of glass. The water used was twice distilled and its pH determined prior to use. The KCl used was an "A.R." reagent.

The experiments were made in three different ways, as follows: (a) By diluting the soil with different quantities of water and shaking for a fixed length of time (3 minutes), according to Gedroiz (5); (b) by preparing the same dilution (1:5) and shaking for different periods of time; and (c) by preparing artificial soils, such as a Ca, a Mg, a K, and a Na soil, diluting them with different concentrations of N/KCl, and measuring the pH in these preparations.

DESCRIPTION OF SOIL SAMPLES

Samples I and II.—These were red sandy soils taken at the colony of Rehoboth in the Southern District of Palestine. The landscape of the red sandy areas can be described as hilly. With the exception of a surface layer (0.50 cm) which is of a darkish color owing to the organic matter it contains, the profile of the sample

[4]The iron salts of strong acids, in general, tend to hydrolyze in solution giving a rather strongly acid reaction.

shows the same structure. Samples were taken at two depths, namely, 0–50 cms and 50–100 cms.

Samples III and IV.—These were dark red loamy soils of the colony of Hederah in the Northern District of Palestine. They belong to the type of soil developed *in situ* on calcareous rocks with a low content of line ($CaCO_3$ less than 0.5%). They were also taken at two depths, namely, 0–50 cms and 50-100 cms.

Sample V.— This was a dark, dull, brown to red lime and clay soil. It was taken in the Jordan Valley west of Allenby Bridge. It consists of a diluvial sediment at the foot of the mountains which has been destroyed in the course of time and overlaid by a layer of alluvial deposit brought down by mechanical processes (wind, rain, etc.). A pit 1 meter deep was excavated and, since the soil was homogenous, one sample was taken from a depth of 0–100 cms.

RESULTS AND DISCUSSION

Since the results of the mechanical and other determinations of samples I and II, on the one hand, and of samples III and IV, on the other hand, were similar, the data recorded in the tables are averages of two samples. Table 1 shows the results of the mechanical analyses made according to the Sudan method worked out by Beam (3). It also records the lime content of the soil.

TABLE 1.— *Mechanical analysis and lime content of the soils.*

Soil No.	Clay (<0.002 mm) %	Silt (0.002-0.02 mm) %	Fine sand (0.02-0.2 mm) %	Coarse sand (0.2-2 mm) %	$CaCO_3$, calculated from CO_2 %
I	5.4	2.4	70.3	21.9	<0.5
II	57.5	15.6	25.4	1.5	<0.5
III	46.8	20.8	20.0	12.4	36.6

Determinations of the pH were made in the case of each of the five soils in water extracts and in normal potassium chloride solutions. Table 2 shows the values of the pH when using the 3-minute extraction method of Gedroiz (5) with six dilutions ranging from 1:1 to 1:160, as conducted by Joseph and Martin (6) in some of their experiments.

TABLE 2. —*The pH values of the soils at different dilutions and for 3 minute extractions.*

Dilution, soil to water	Water extract			N/KCl extract			Difference		
	Soil No. I	Soil No. II	Soil No. III	Soil No. I	Soil No. II	Soil No. III	Soil No. I	Soil No. II	Soil No. III
1:1....	6.8	8.0	8.1	6.65	7.3	7.5	0.15	0.7	0.6
1:5..........	7.15	8.3	8.5	6.75	7.3	7.9	0.4	1.0	0.6
1:10.........	7.2	8.4	8.5	7.05	7.3	8.1	0.15	1.1	0.4
1:40.........	7.1	7.85	8.5	7.05	7.3	8.5	0.05	0.55	0.0
1:80.........	7.3	7.7	8.5	7.10	7.3	8.6	0.2	0.4	0.1
1:160........	7.1	7.4	8.6	7.1	7.3	8.6	0.0	0.1	0.0

Table 3 shows the pH values of the soils, using a 1:5 dilution with five periods of extraction ranging from 3 minutes to 8 days.

TABLE 3.—*The pH values of the soils with different extraction periods.*

Extraction period	Water extract			N/KCl extract			Difference		
	Soil No. I	Soil No. II	Soil No. III	Soil No. I	Soil No. II	Soil No. III	Soil No. I	Soil No. II	Soil No. III
3 mins.	7.15	8.3	8.5	6.75	7.3	7.9	0.4	1.0	0.6
1 hour....	7.1	8.0	8.3	7.1	7.3	7.9	0.0	0.7	0.4
1 day....	7.1	8.2	8.3	7.1	7.6	7.9	0.0	0.6	0.4
2 days..	7.1	8.1	8.3	6.9	7.5	7.9	0.2	0.6	0.4
4 days .	7.3	8.0	8.1	6.9	7.5	7.9	0.4	0.5	0.2
8 days ...	7.1	8.0	8.1	6.9	7.5	8.1	0.2	0.5	0.0

Table 2 shows that the greatest reduction in pH caused by the addition of a neutral salt occurred in heavy soils. In these soils the reduction reached 1.1 in the 1:10 dilution, but decreased with further dilutions. The two light soils in a 1:5 dilution showed a decrease of 0.40 in the pH values, with further diminution on greater dilution. The calcareous soils showed a lowering of 0.6 in pH vlaues in dilutions of 1:1 and 1:5, while the value decreased still more on further dilution.

In Table 3 it will be noted that neutral salts influenced the pH value most in the case of heavy soils the difference being 1.0 after 3 minutes but lessening with increasing time of extraction. In light soils the pH values were equal after 3 minutes and 4 days (0.4). In calcareous soils the difference in pH was 0.6 after 3 minutes, but remained constant from 1 hour to 2 days (0.4), but decreasing with longer periods of time.

In order to ascertain the influence of the exchangeable cations Ca, Mg, K, and Na on the addition of a neutral salt, the light and heavy soils described above were prepared by treating them with 0.05 N/HCl until they completely lost the above-mentioned cations. The soils were then treated separately with N/$CaCl_2$, $MgCl_2$, KCl, and NaCl, shaken for 24 hours, and washed with distilled water until they became completely free of chlorine. Next, each sample was dried until free of moisture. In order to determine the pH in these specially prepared samples and the influence of neutral salts on them, they were tested with water and N/KCl. Further, the changes undergone by the pH were ascertained by adding different quantities of N/KCl. The results are given in Table 4.

From the results obtained it may be concluded that (a) heavy soils with exchangeable bases always show a higher pH than light soils; and that (b) in a water extract of 1:5 the pH values of different soils with monovalent or bivalent cations decreased with an increase in the atomic weight of the cations and are lower in the case of bivalent cations than in the case of the monovalent cations; (c) that on the addition of different quantities of N/KCl the pH value diminishes in all soils with an increase in KCl, and in heavy soils the diminution is greater than in light soils; and (d) that so far as the influence of

TABLE 4.—*The hydrogen-ion concentrations in water extract (1:5) of artificially prepared soils, quantities of N/KCl and the differences between them.*

N/KCl:H_2O	Ca soil				Mg soil			
	Light	Diff.	Heavy	Diff.	Light	Diff.	Heavy	Diff.
0:25	7.2	0.0	7.4	0.0	7.1	0.0	7.3	0.0
1:24	7.2	0.0	7.4	0.0	7.1	0.0	7.3	0.0
5:20	7.2	0.0	7.4	0.0	7.1	0.0	7.3	0.0
10:15	7.2	0.0	7.4	0.0	7.1	0.0	7.2	0.1
15:10	7.15	0.05	7.3	0.1	7.0	0.1	7.0	0.3
20:5	7.1	0.1	7.2	0.2	6.9	0.2	6.8	0.5
25:0	7.0	0.2	6.9	0.5	6.8	0.3	6.6	0.7
N/KCl:H_2O	**K soil**				**Na soil**			
	Light	Diff.	Heavy	Diff.	Light	Diff.	Heavy	Diff.
0:25	6.8	0.0	7.0	0.0	7.3	0.0	7.5	0.0
1:24	6.8	0.0	6.8	0.2	7.3	0.0	7.3	0.2
5:20	6.6	0.2	6.6	0.4	7.0	0.3	7.0	0.5
10:15	6.5	0.3	6.4	0.6	6.6	0.7	6.7	0.8
15:10	6.5	0.3	6.3	0.7	6.5	0.8	6.4	1.1
20:5	6.4	0.4	6.1	0.9	6.2	1.1	6.0	1.5
25:0	6.2	0.6	5.8	1.2	6.1	1.2	5.6	1.9

KCl on the reaction and its specific influence on the stability of the complex are concerned, Ca soils are most stable, with Mg and K soils next in order, and Na soils last.

SUMMARY

The following conclusions may be drawn from the experiments reported here

1. The observation that the pH value of a soil is lowered on the addition of a neutral salt is valid not only in the case of humid soils but also in arid soils. We cannot speak here of saturated and unsaturated soils, only more or less saturated soils. All the processes which render humid soils unsaturated also take place in arid climates, but much less intensively.
2. Analytical data confirm the fact that the dilution of 1:5 and an extraction time of 3 minutes give optimum results
3. On the addition of a neutral salt, the pH value diminishes most in heavy soils and least in light soils.
4. A close relation exists between the position and valency of the absorbed complex and the pH of the soil.
5. In preparing different types of soils, such as Ca, Mg, K, and Na soils, it was observed that bivalent soils, i.e., Ca and Mg soils, were less affected by the addition of neutral salts than the monovalent types, i.e., K and Na soils. Also, Ca soil was less affected than Mg soil and K soil than Na soil.
6. The fact that the addition of a mineral fertilizer to the soil causes a diminution of the pH in the soil is of immense importance to the practical agriculturist. By examining the exchange of bases in the

soil, he can arrive at an accurate estimate of the extent to which the soil would be affected by the addition of a mineral fertilizer and what means should be taken, e.g., addition of lime, in order to prevent the accumulation of acids in the soil.

LITERATURE CITED

1. AARNIO, B. Influence of absorbed ions on soil reaction. Bul. Agrogeolog. Inst., Finland, 6. 1927.
2. ARRHENIUS, O. Die Einwirkung neutraler Salze auf die Bodenreaktion. Proc. Int. Soc. Soil Sci., 25–35. 1926.
3. BEAM, W. Sudan method. Cairo Sci. Jour., 107–119. 1911.
4. GALLAY, R. Beitrag zur Kenntnis der Tonkoagulation. Kolloidchem. Beihefte, 21:431–489. 1925.
5. GEDROIZ, K. K. Lehrbuch der Bodenanalyse. Verlag Gebr. Borntrager, 147–177. 1932.
6. JOSEPH, A. F., and MARTIN, F. I. The hydrogen-ion concentration of heavy alkaline soils. Jour. Agr. Sci., 13:321–332. 1923.
7. KÜHN, S. Zeitschr. pflanzl. Dungung., 18A:309–314. 1930.
8. MCBAIN, J. W., and COLMAN, F. Ch. A criticism of the hypothesis of weak acids and bases. Zeitschr. Phys. Chem., 2:201. 1888.
9. MICHAELIS, L., and RONA, P. Der Einfluss der Neutralsalze auf die Indikatoren. Biochem. Zeitschr., 23:61. 1910.
10. PUFFELES, M. A preliminary survey of soils in the Jordan Valley. Hadar, 9:16–17. 1936.
11. Sorensen, S. P. L., and PALITZSCH, S. Ueber die Messung der Wasserstoffionen-Konzentration des Meerwassers. Biochem. Zeitschr., 24:387. 1910.
12. ———, ———. Ueber den "Salzfehler" bei der kolorimetrischen Messung der Wasserstoff-ionen-Konzentrationdes Meerwassers. Biochem. Zeitschr., 51:307. 1913.
13. WEIGNER, G. Dispersitat und Basenaustausch (Ionenaustausch). Zsigmondy-Festschrift, Erg. Bd. 7, Kolloid-Zeitschr., 36:341–369. 1925.
14. ———. Ionenaustausch und Struktur. Trans. Third Congress Soil Sci., 3:5–28. 1936.
15 ———, GALLAY, R., and GESSNER, H. Wasserbindung im Boden. Kolloid-Zeitschr., 35:313–322. 1924.

THE GROWTH OF KENTUCKY BLUEGRASS AND OF CANADA BLUEGRASS IN LATE SPRING AND IN AUTUMN AS AFFECTED BY THE LENGTH OF DAY[1]

MORGAN W. EVANS AND JAMES M. WATKINS[2]

THIS report is devoted chiefly to a study of the effects of length of day upon the seasonal habits of growth of Kentucky bluegrass (*Poa pretensis* L.) and of Canada bluegrass (*Poa compressa* L.). No critical studies were made of the effects of variations in temperature aside from the effects of those differences occurring naturally at the two seasons when experiments were conducted. It is recognized, however, that the habits of growth of these species of grass may be affected by temperatures (4).[3]

Plants of both Kentucky bluegrass and of Canada bluegrass, grown under the natural photoperiods of late spring and early summer in the latitude of Wooster, Ohio, produce upright shoots. Similar plants grown under the natural photoperiods prevailing during fall and early spring, on the other hand, produce decumbent or semi-decumbent shoots. In rhizome production the two species differ from each other at both of these periods.

Plants of Kentucky bluegrass grown at these two periods are illustrated in Fig. 1. The plant which made its growth in spring and early summer produced relatively few shoots, both shoots and leaves growing in a more or less upright position. Two underground stems or rhizomes were produced. The plant which made its growth in the fall produced a larger number of shoots, but both stems and leaves grew in decumbent or semi-decumbent positions and no rhizomes developed.

At the latitude of Wooster, Ohio, during the time when the experiment was conducted in late spring and early summer, the length of day, from sunrise to sunset, gradually increased from 14.5 hours on May 17 to 15.1 hours on June 10, remained at approximately this length until July 2, then decreased to 15.0 hours. In the experiment conducted in the fall the length of day gradually decreased from 12.3 hours on September 20 to 10.1 hours on November 9. In the spring the average length of day was 15.0 hours; in the fall it was 11.2 hours (3, pages 6–7). From May 17 to July 6 the mean daily temperature was 67° F, and from September 20 to November 9, 52° F. No records were obtained of the night temperatures within the boxes used to cover the short-day plants. Presumably these temperatures were

[1]Paper delivered by the senior author on May 6, 1938, before the Botanical Section of the Ohio Academy of Science. The investigation was conducted at Wooster, Ohio, by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication June 8, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 773.

modified to some extent during the 15.5 hours that the plants were covered.

EXPERIMENTAL METHODS

On May 17, 1937, typical plants of Kentucky bluegrass and of Canada bluegrass, grown from commercial seed sown August 24-25, 1936, were transplanted to three separate sets of duplicate plats. In these plats, each of which was approximately 4 x 4 feet, the rows were 1 foot apart and the plants 6 inches apart in the rows. Final records were obtained from 21 plants in each plat, or from 42 for each treatment.

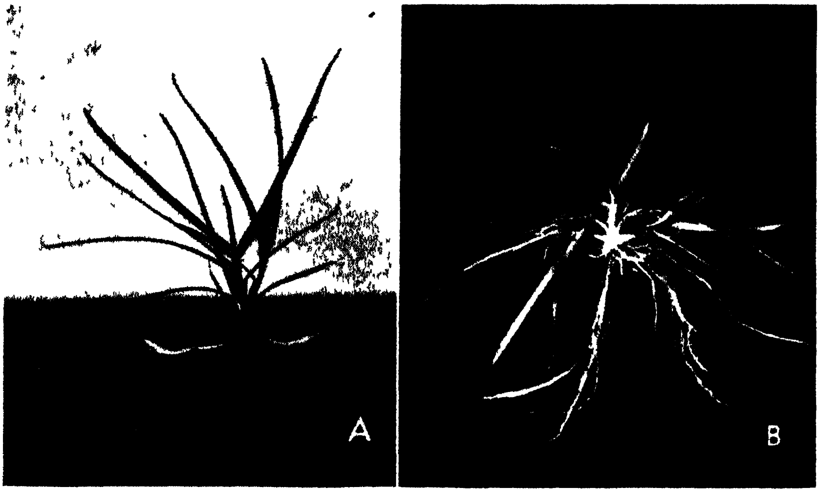

FIG. 1.- Typical young plants of Kentucky bluegrass grown under natural illumination. A, collected July 9, 1937, B, collected November 24, 1937.

One set of duplicate plats grew with normal daily illumination. The second set of plats was artificially illuminated for a sufficient length of time after sunset so that they received light approximately 18 hours each day. For this purpose 12 mazda 200-watt electric light bulbs, automatically controlled by an electric time clock, were used. They were arranged in two rows of six lights each, 4 feet above the ground and spaced 4 feet from center to center. At the surface of the soil the illumination ranged from approximately 65 to 80 foot-candles throughout the area occupied by these plats.[4] Each plat in the third set was covered part of each day with a box measuring approximately 4 x 4 x 4 feet and painted black inside and white outside. There were in each box two 4-inch curved ventilating pipes placed at different levels at the rear, painted black inside so that they admitted no light. The boxes were kept over the plants from 4:30 p.m. until 8:00 a.m. These plants, therefore, received 8.5 hours illumination daily.[5]

[4]Acknowledgments for measurements of the intensity of illumination at night under the electric lights are due to J. P. Ditchman, Nela Park Engineering Department, General Electric Company, Cleveland, Ohio.

[5]Helpful suggestions and advice in regard to the method and equipment used for growing the plants under the different lengths of day were received from H. A. Allard, Division of Tobacco and Plant Nutrition Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture.

Since, with the equipment at hand, there was no way in which the artificial light used at night on the long-day plats could be effectively screened off from the adjacent areas, it was necessary to place the check plats of plants grown under natural illumination at some distance. The two sets of plats were 325 feet apart. The short-day plats were in an area adjoining the check plats. Both groups of plats were located on similar slopes. Between them was an 8% slope which helped to prevent the electric light rays from reaching the check plats. Where the long-day plats were located the slope was about 4%. In the other location it was about 3%. In each location the soil was the Wooster silt loam, with the A horizon about 12 to 14 inches deep.[6] Soil conditions, therefore, were closely similar in all plats.

The lights and the dark boxes were used from May 17 to July 6. The data for this experiment were recorded on July 9.

A second similar experiment was conducted in these plats in the fall of 1937. The seed was sown on August 19 in rows 8 inches apart. The plants were thinned about September 20 to a distance of approximately 4 inches apart. The lights and the dark boxes were used from September 20 to November 26. Final records of the numbers of shoots and rhizomes were obtained from 28 plants under each treatment - with the exception that records were obtained from only 14 plants of Kentucky bluegrass grown under long days. The average degree of elevation of the shoots were based on measurements of from 45 to 60 shoots for each treatment —with the exception of Kentucky bluegrass grown under long days, for which the average degree of elevation is based on measurements of 27 shoots.

Standard errors were computed for the data on shoots and rhizomes for both experiments. The following comparisons were made for each species: Long with natural day, long with short day, and natural with short day. The level of significance was determined from Livermore's (2) "t" table.

HABITS OF GROWTH OF ABOVE-GROUND PARTS OF PLANTS AS AFFECTED BY LENGTH OF DAY

EXPERIMENT CONDUCTED IN LATE SPRING AND EARLY SUMMER

Records in Table 1 show the habits of growth of plants of Kentucky bluegrass grown during spring and early summer, under natural lengths of day, under days 18.0 hours long, and under days 8.5 hours long. Under long days the shoots grew in an upright position, like those produced under natural lengths of day The number of shoots per plant under long days was about two-thirds as great as on plants grown under natural lengths of day, but only about one-third as great as on the plants grown under short days. The plants grown under short days, compared with those grown under natural conditions, had about twice as many shoots per plant, and they grew in more nearly decumbent positions. Under all lengths of day the percentage of shoots producing inflorescences was small. This may be related, at least to some extent, to the small size in early spring of the plants which had developed from seed sown in the preceding August.

Fig. 2 illustrates the upright habit of the plants of Kentucky bluegrass grown under 18.0 hours illumination, and the procumbent positions of the shoots when the plants were grown under 8.5 hours daily

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[6]Acknowledgments are due Mrs. Elizabeth B. Mickelson of the Department of Agronomy, Ohio Agricultural Experiment Station, for the description of the topography and of the soil where this experiment was conducted.

illumination. Table 1 shows that on the plants of this species under long days the number of shoots was reduced and under short days the number of shoots was much greater than on plants grown under natural lengths of day. Significant differences were obtained from all comparisons on the number of shoots per plant under the three lengths of day. The only significant difference obtained on the length of shoots was between the long- and short-day plants.

TABLE 1.—*Records of plants of Kentucky bluegrass and of Canada bluegrass grown in the spring of 1937 under natural, long, and short days.*

Length of day	Shoots			Rhizomes		Ratio of number shoots to rhizomes
	Average per plant		Average length of longest*, mm	Average number per plant	Average length of longest, mm	
	Total number	With inflorescences, %				
			Kentucky Bluegrass			
Natural day	31	2	317	52	130	100:167
Long day	20	5	353	38	110	100:190
Short day	61	2	285	41	128	100:67
			Canada Bluegrass			
Natural day	55	40	440	27	84	100:49
Long day	35	65	472	8	45	100:23
Short day	80	8	186	18	65	100:22

*Records of lengths were made only of those shoots with inflorescences

The effects of the lengths of day upon the plants of Canada bluegrass were much the same as upon the plants of Kentucky bluegrass. Under short days the number and percentage of Canada bluegrass shoots with inflorescences were less than on plants grown under long or under natural lengths of day. On the plants grown under both natural and long days, the inflorescences were normal; under short days spikelets with proliferations occurred on 78% of them. The differences in the total number of shoots between any two lengths of day were found to be highly significant. In comparisons of length and

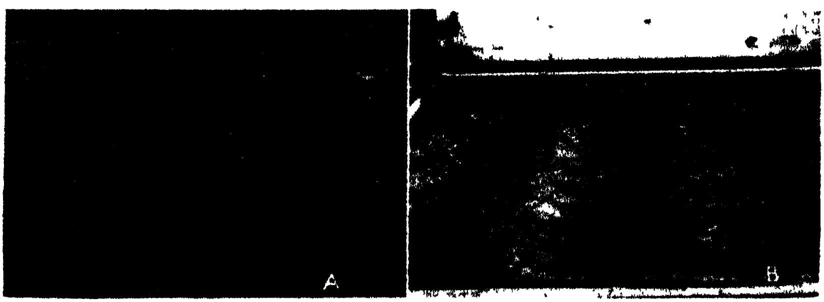

FIG. 2.—Kentucky bluegrass, June 30, 1937. A, plants grown with 18 hours daily illumination; B, plants grown with 8.5 hours daily illumination.

number of shoots with inflorescences, the short-day plants were found to be significantly different from the natural- and long-day plants

EXPERIMENT CONDUCTED IN THE FALL

On the plants of both species grown in the fall under days approximately 18 hours long, the stems resembled those grown under natural lengths of day in late spring in having both shoots and leaves which tend to grow in an upright position The number and length of shoots per plant on long-day plants were found to be significantly different from short- and natural-day plants Table 2 shows that the average elevation of the stems on plants grown under long days was 69 degrees above the horizontal for Kentucky bluegrass and 47 degrees above the horizontal for Canada bluegrass Under short days, this elevation was 23 and 20 degrees, respectively Under the natural lengths of day occurring in late November, the shoots were appressed toward the soil almost as much as on the plants grown under 8 5 hours daily illumination

TABLE 2 *Growth of Kentucky bluegrass and of Canada bluegrass as affected by different lengths of day* *

Length of day	Shoots: Average per plant: Total number	Shoots: Average per plant: Length of longest†, mm	Shoots: Degrees elevation above the surface of the soil	Average number of rhizomes per plant
	Kentucky Bluegrass			
Natural day	8 9	15	28	0 3
Long day	4 1	86	69	0 7
Short day	10 9	14	23	0 2
	Canada Bluegrass			
Natural day	10 7	18	22	0 9
Long day	7 5	75	47	0 5
Short day	10 9	17	20	1 5

*The records were obtained November 20 1937, from plants grown from seed sown August 19, 1937

†The length of each shoot was measured from its base to the juncture of the sheath and blade of the uppermost leaf None of the shoots on these plants grown in the fall had produced inflorescences

Under days 8 5 hours long, the habits of growth of the plants of both species closely resembled those of the plants grown under natural lengths of day at this season of the year The shoots were short and more or less decumbent and had the form of growth commonly described as rosette Hurd-Karrer (1) induced this habit of growth in winter wheat by reducing the length of day to 8 hours both on plants grown under temperatures ranging from 10° to 12° C and also under temperatures ranging from 20° to 23° C.

DEVELOPMENT OF RHIZOMES AT DIFFERENT SEASONS AS AFFECTED BY LENGTH OF DAY

In the length-of-day experiment extending from May 17 to July 6, as shown in Table 1, there was little difference in the number of

rhizomes[7] per plant of Kentucky bluegrass under 18.0 hours and under 8.5 hours daily illumination. The normal day plants were significantly different in this respect from both the short day and the long day plants. The ratio of rhizomes to shoots, however, was nearly three times as great on the plants grown under long days as on those grown under short days. The number of rhizomes on Canada bluegrass plants was greatest when grown under natural days; however, plants from each length of day were found to be significantly different from each other in number of rhizomes produced. On the Canada bluegrass plants the ratio of rhizomes to shoots was practically the same under long and under short days, but the plants grown under an 18-hour day had only 8 rhizomes per plant while those grown under 8.5 hours daily illumination had 18 rhizomes per plant.

In the plats seeded on August 19, the Kentucky bluegrass produced, as shown in Table 2, 0.7 rhizomes per plant under days 18.0 hours long. This number was reduced to 0.2 under days 8.5 hours long. Canada bluegrass produced, under the longer day, an average of 0.5 rhizome per plant while under the shorter day this number was increased to 1.5.

In respect to the lengths to which the rhizomes grew under short and under long days in neither experiment and for neither species do the records show any very definite trends.

In another set of plats sown August 24-25, 1936, records of the number of rhizomes were obtained from either 5 or 10 plants, with the exception that only 3 plants of Canada bluegrass were examined on April 15, on different dates in the spring of 1937. On the plants of Kentucky bluegrass the following average numbers of rhizomes per plant had developed on these dates; March 22-23, 0 0, April 5, 0 4; April 15, 0.2; April 30-May 1, 0.0; May 15, 6.4 On the plants of Canada bluegrass, the average numbers of rhizomes per plant were as follows: March 22–23, 0.4; April 5, 3.4; April 15, 8.6; May 15, 11.8. These data show that the plants of Kentucky bluegrass produced very few rhizomes up to May 1, after which time there was a rapid increase in their numbers. On the plants of Canada bluegrass, on the other hand, beginning with 0.4 rhizome per plant on March 22–23, there was a gradual increase in their numbers, and by May 15 there were approximately 12 per plant.

On typical plants from other plats of both species sown on April 24, 1937, there was by July 9 an average of 3.2 rhizomes per plant on Kentucky bluegrass plants and an average of only 0.7 rhizomes per plant on Canada bluegrass plants.

In the various experiments at Wooster, Ohio, which have been described, young plants of Kentucky bluegrass produced few rhizomes during late fall or very early spring. They did not begin development in large numbers until May. Young plants of Canada bluegrass, on the other hand, produced relatively large numbers of rhizomes both in late autumn and in very early spring; relatively few began their

[7]In this paper, a rhizome refers to an underground stem having one or more elongated internodes. The rhizome may be either a primary one or a branch, and it may or may not be terminated by an above-ground shoot, though in these experiments few or none of the rhizomes had produced shoots.

growth in late spring and early summer. The data from plants grown under days of different lengths indicate that the difference in the seasonal growth of the rhizomes of these two species is largely due to the tendency for Kentucky bluegrass rhizomes to develop in greatest numbers under relatively long days, and for the rhizomes of Canada bluegrass to grow in largest numbers under short days.

SUMMARY AND CONCLUSIONS

Plants of Kentucky bluegrass and of Canada bluegrass were grown from May 17 to July 6, 1937, under natural lengths of day and under days with 18.0 hours and with 8.5 hours daily illumination. During this period the mean daily temperature was 67° F, and the average length of natural photoperiod was 15.0 hours. A similar experiment was conducted from September 20 to November 26, 1937, with a mean daily temperature of 52° F and an average length of day of 11.2 hours.

Under the relatively long days of late spring and early summer, on the plants of both species the shoots were nearly upright, the internodes became elongated, and on some of the shoots inflorescences developed. On the plants grown under the relatively short days during the fall, the shoots grew in decumbent or semi-decumbent positions, the stems were not elongated, and no inflorescences developed. Likewise, on the plants illuminated for 18.0 hours daily, both in late spring and early summer and also in the fall, irrespective of the differences in temperatures at these seasons, the shoots grew in upright or nearly upright positions and to relatively great lengths. In the spring, particularly on plants of Canada bluegrass, a large proportion of the shoots produced inflorescences. On the plants illuminated 8.5 hours daily, the shoots grew in decumbent or semi-decumbent positions, the internodes of the stems were not elongated, and few or no inflorescences developed.

The rhizomes of Kentucky bluegrass developed in greater numbers during late spring and early summer than in late fall and early spring. Under experimental conditions in late spring the ratio of rhizomes to shoots was about three times as great, and in the fall the number of rhizomes per plant was much greater under long days than under short days. The rhizomes of Canada bluegrass developed in greatest numbers in late fall and early spring. Under experimental conditions at both times, greater numbers of rhizomes developed under short days than under long days.

The distinguishing habits of growth of plants of Kentucky bluegrass and of Canada bluegrass during late spring and early summer are due primarily to the relatively long days occurring then. Likewise, the habits of growth peculiar to the fall season are due primarily to the short days occurring at that time.

LITERATURE CITED

1. HURD-KARRER, A. M. The formative effect of day length on wheat seedlings. Jour. Md. Acad. Sci., 1:115–126. 1930.

2. LIVERMORE, J. R. The interrelations of various probability tables and a modification of Student's probability table for the argument "t". Jour. Amer. Soc. Agron., 26:665-673. 1934
3. MARVIN, C. F. Sunshine tables, part III. W. B. No. 805; Weather Bureau, U. S. Dept. of Agriculture. 1905.
4. ROBERTS, R. H., and STRUCKMEYER, B. E. The effect of temperature and other environmental factors upon the photoperiodic responses of some of the higher plants; Jour. Agr. Res., 56:633-677 1938.

A SIMPLE MEASURE OF KERNEL HARDNESS IN WHEAT[1]

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ANY simple test that will aid the wheat breeder in measuring characteristics of grain is of value in increasing the efficiency of the breeding program. In the eastern soft wheat region hard wheats are being used extensively as parents to secure resistance to various diseases and a simple test is especially needed for identifying, in the early generations, hybrid lines with soft grain. Hard wheats in general produce coarse granular flour and soft wheats fine smooth flour. The particle size index test developed by Cutler and Brinson[3] appears to differentiate varieties in a very satisfactory way so far as this character is concerned. It is slow, however. The doughball time test has also been suggested by Cutler and Worzella[4] as a measure of quality for small samples. Since the degree of granulation of a flour seems to be related to hardness of the grain, it occurred to the authors that a pearler such as is used in the inspection of barley and which has also been used for studies in the milling of parboiled rice, might be useful in estimating the hardness of wheat samples. Some preliminary trials seemed to verify this assumption and hence a more extensive investigation was planned and carried out The results appear promising enough to justify presenting the results.

MATERIALS AND METHODS

The pearler consists of an enclosed grinding stone attached to a 1/8 h. p. direct-drive electric motor. An interval timer, a balance sensitive to 0.01 gram, and a set of Tyler screens completes the apparatus necessary for the pearling test.

Preliminary tests were made on grain of varieties grown in field plats at the Arlington Experiment Farm, Arlington, Va. Later samples from the varieties in the uniform soft winter wheat nurseries grown at several stations in the eastern states were studied. Also, in order to obtain data with a wider range of kernel types, samples of a few winter and spring varieties grown in field plats at experiment stations in the western United States were included.

The wheat was stored for two months or more prior to pearling in an ordinary seed storage room. The moisture in the grain varied between 10 and 11% and no shriveled or badly broken grain was used. The procedure used in the test was as follows:

1. Approximately 100 grams of wheat were placed on a No. 6 Tyler screen held over a No. 8. After shaking a definite number of times by hand, three 20-gram samples were weighed from the grain remaining on the No. 8 screen.

2. A sample was placed in the pearler and the latter started and run exactly 3 minutes.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication June 15, 1939.

[2]Agronomists and Associate Baking Technologist, respectively.

[3]Cutler, G. H., and Brinson, G. A. The granulation of whole wheat meal and a method of expressing it numerically. Cereal Chem., 12:120-129. 1935.

[4]Cutler, G. H., and Worzella, W. W. A modification of the Saunders' test for measuring "quality" of wheats for different purposes. Jour. Amer. Soc. Agron., 23:1000-1009. 1931.

3. The grain and rubbed-off material were removed from the machine, screened on a No. 20 screen, and the grains riding the screen weighed to the hundredth gram. From this weight the percentage pearled off was calculated.

EXPERIMENTAL RESULTS

Table 1 gives the percentage pearled off of seven varieties of wheat grown at Arlington Farm in each of five years. The averages show little difference between Kawvale and Purkof. Red Rock could be separated from them each year by the difference in pearling results. Forward, though classed as soft red winter, is decidedly harder by this test than Leap, Trumbúll, or Nittany. The last three varieties are considered among the softest of the red winter varieties and probably rank in softness in the order shown.

TABLE 1.—*Percentage of kernels pearled off of seven varieties of soft red winter wheat grown in each of five years at the Arlington Experiment Farm, Arlington, Va.*

Variety	Year and percentage of grain pearled off					
	1934	1935	1936	1937	1938	Average
Purkof	25.5	25.1	23.9	22.0	20.8	23.5
Kawvale	23.8	23.6	22.4	27.9	22.0	23.9
Red Rock	32.1	27.5	27.7	28.0	24.6	28.0
Forward	33.4	30.9	30.3	33.4	26.4	30.9
Trumbull	37.5	35.3	33.2	33.2	30.9	34.0
Nittany	39.9	35.1	35.8	34.8	31.9	35.5
Leap	39.3	35.1	37.9	37.8	32.5	36.5

The results of a more extensive study involving 27 varieties grown in the uniform soft winter wheat nurseries in 1936 at five stations, *viz.*, Lincoln, Neb.; Urbana, Ill.; Ithaca, N. Y.; Kearneysville, W. Va.; and Arlington, Va., are presented in Table 2. Each pearling value given is an average of three determinations. Index of particle size from the same lots of grain grown at Ithaca and Kearneysville and doughball time for those grown at Urbana and Kearneysville are also given for comparison. Index of particle size is based on single determinations only and doughball time is an average of four determinations. Generalized standard errors for the pearling test are also given in Table 2. The figures given are the standard errors of the mean applicable to the determination for each individual variety. Inspection of the data indicated no relation between standard errors and percentage pearled off and consequently generalized standard errors are believed to be reliable for the purposes for which they are used. In this table varieties are arranged in the order of softness of grain as indicated by the pearling test.

The relative ranking of the varieties for particle size index and doughball time is in close agreement with the results obtained by Worzella and Cutler[5] for the same varieties grown at Lafayette, Ind.

[5]WORZELLA, W. W., and CUTLER, G. H. Character analysis of winter wheat varieties. Jour. Amer. Soc. Agron., 30:430–433. 1938.

TABLE 2.—*Percentage of grain pearled off from 27 varieties of wheat grown at five stations in 1936, and the particle size index and dough-ball time at two stations.*

Variety*	C. I. No.	Station and percentage pearled off						Station and particle size index		Station and dough-ball time†	
		Lincoln	Urbana	Ithaca	Kearneys-ville	Arlington	Av.	Ithaca	Kearneys-ville	Urbana	Kearneys-ville
Nittany	6962	38.7	35.3	35.9	38.3	35.8	36.8	35.2	33.0	72	43
Goldcoin	6971	35.1	34.7	41.7	37.0	34.7	36.6	37.0	33.6	26	25
Dawson	6943	36.8	34.3	38.0	40.8	32.2	36.4	35.2	34.8	31	26
Fulhio	6999	37.3	35.7	38.8	35.1	35.0	36.4	39.0	35.4	50	43
Honor	6161	36.5	34.1	38.2	38.3	33.2	36.1	37.6	35.0	30	26
Valprize	11539	37.2	37.1	32.3	37.9	34.1	35.7	35.2	35.4	48	42
Trumbull	5657	37.8	34.1	36.9	34.3	33.2	35.3	33.8	34.0	53	43
Rudy	5656	36.6	33.4	33.1	35.9	33.3	34.5	32.4	29.8	68	40
Currell	3326	37.3	33.5	33.1	32.9	33.4	34.0	39.6	30.8	56	45
Gladden	5644	35.3	33.7	30.9	33.8	31.9	33.1	36.4	35.0	43	33
Illinois No. 2	11537	33.8	33.4	30.2	31.2	31.6	32.0	31.0	31.4	122	104
Nabob	8869	30.8	33.7	29.9	32.3	30.6	31.5	27.4	29.6	61	42
Purdue No. 1	11380	30.6	32.6	31.0	31.7	31.0	31.4	31.2	34.4	60	48
Fulcaster	6471	34.1	31.0	27.6	33.0	28.0	31.2	27.8	28.4	58	41
Forward	6691	33.3	29.5	29.4	29.8	30.3	30.5	29.6	28.0	67	45
Mediterranean selection	11567	30.5	29.9	32.4	31.3	27.3	30.3	33.4	31.2	47	35
Harvest Queen	6199	30.9	30.9	28.6	31.5	29.4	30.3	31.2	30.6	56	49
Baldrock	11538	30.7	30.3	26.9	31.0	30.8	29.9	25.2	25.6	68	47
Red Rock	6951	34.5	30.4	28.3	28.8	27.7	29.9	32.2	26.2	100	51
Poole	3488	30.8	29.1	28.0	29.4	29.3	29.3	31.4	29.2	61	44
Wisconsin Pedigree 2	6683	29.6	30.0	27.7	28.6	28.3	28.8	28.0	27.4	103	73
Michigan Amber	5620	28.5	29.0	27.5	28.3	27.0	28.1	27.2	27.6	90	71
Minhardi	5149	28.3	27.8	25.5	25.4	26.1	26.6	36.2	26.4	141	66
Minturki	6155	27.6	28.1	23.8	26.6	24.4	26.1	26.8	24.0	163	119
Kawvale	8180	23.8	24.6	20.8	26.2	22.4	23.6	17.0	18.2	154	106
Purkof	8381	23.0	21.0	19.1	22.3	23.9	21.9	20.0	20.8	179	153
Kharkof	1442	22.4	21.7	20.4	23.2	21.2	21.8	19.8	21.0	109	86
Station average		32.3	31.1	30.2	31.7	29.9		31.0	29.5	78.4	57.3
Standard error of varietal means		0.050	0.064	0.107	0.102	0.050					

*All varieties listed are soft red winter varieties with the exception of Goldcoin, Dawson, and Honor, which are white winter varieties, and Wisconsin Pedigree 2, Minturki, and Kharkof, which are hard red winter varieties.

†Made by Dr. E. G. Bayfield of Wooster, Ohio, and are the averages of four 4-gram doughballs.

The order of the varieties with respect to pearling is in substantial agreement with their supposed or known hardness of grain. Thus all the hard and semihard winter wheats are at the bottom of the table, and recognized soft wheat varieties are at the top, with others generally recognized as intermediate in the middle. It might be expected that since Nittany originated as a selection from Fulcaster it should resemble the latter in grain hardness. Observations other than those presented herein have indicated it to be softer than Fulcaster.

The interstation correlation coefficients for the percentage pearled off for five stations, for particle size index for two stations, and for doughball time for two stations are given in Table 3. The correlations for pearling and particle size at two stations and for pearling and doughball time at two stations are also given. These were calculated from the data of Table 2. The ten interstation correlation coefficients for pearling are, with one exception (Ithaca vs. Lincoln r=0.863), above 0.9. This indicates that the relative hardness of the grain of the different varieties as measured by the pearling test was much the same regardless of where it was grown

TABLE 3.—*Correlation coefficients of percentage pearled off, particle size index, and doughball time for grain of 27 wheat varieties grown at several experiment stations.*

Characters correlated and station where grown	Kearneysville	Urbana	Ithaca	Lincoln
Pearling vs. pearling:				
Arlington	0.922	0.929	0.917	0.929
Kearneysville	—	0.936	0.921	0.906
Urbana	—	—	0.920	0.958
Ithaca		—		0.863
Particle size vs. particle size:				
Kearneysville	—	—	0.857	-
Doughball time vs. doughball time:				
Kearneysville		0.936	-	—
Pearling vs. particle size index	0.857	—	0.835	—
Pearling vs. doughball time	−0.769	0.755	—	-

Least highly significant value (P=0.01) of r for 27 varieties =0.4869

The interstation coefficients for particle size and for doughball time were also high, r=0.857 and 0.936. The lower coefficient for particle size is due, in part at least, to what appears to have been an error in making the determination on Minhardi from Ithaca. This figure is not in line with the other data in this study nor with the results of Worzella and Cutler[6] who also found this variety to give a relatively low index.

The coefficients for pearling vs. particle size for Kearneysville and Ithaca are 0.857 and 0.835 and those for pearling vs. doughball time for Kearneysville and Urbana are −0.769 and −0.755. Reference to Table 2 and Fig. 1, which shows the percentage pearled off, the particle size index, and the doughball time for the varieties grown at Kearneysville, indicates that somewhat lower coefficients for pearling

[6]See footnote 5.

vs. doughball time are due largely to a few varieties, such as Illinois No. 2, which has a longer doughball time, and Kharkof, which has a shorter doughball time, than the other characters would indicate.

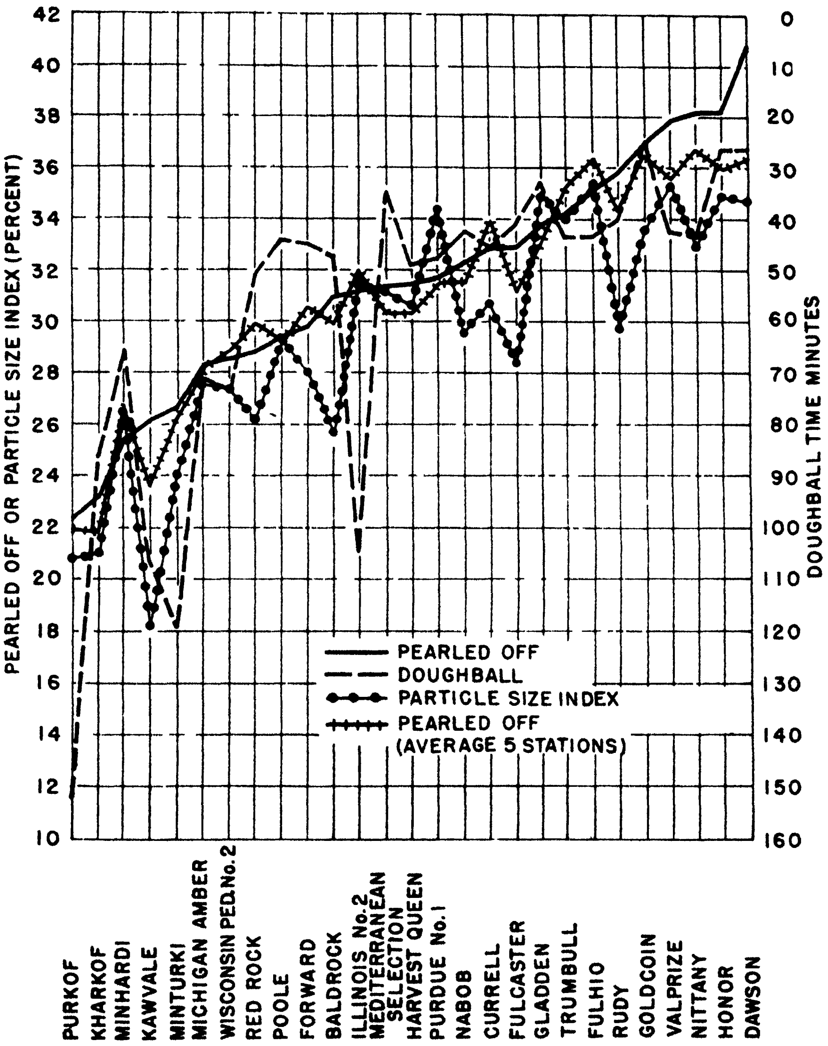

FIG. 1.- Percentage of kernel pearled off, particle size index, and doughball time for 27 varieties of winter wheat grown at Kearneysville, W. Va., and average percentage pearled off for the same varieties grown at four other stations.

No reasons for the lack of agreement for these particular varieties are known, but these and other data seem to justify the conclusion that the differences are varietal and not due to random errors.

TABLE 4.—*Percentage of grain pearled off, particle size index, doughball time, and percentage of protein for samples of spring wheat varieties grown in the western states.*

Item	Marquis	White Federation	Baart	Onas	Federation	Pacific Bluestem	Irwin Dicklow	Lemhi	Av. of 5 varieties	Av. of 8 varieties
1935 Dryland Composite*										
Pearled off, %	22.6	26.4	36.2	36.8	38.6	—	—	—	32.1	—
Particle size index	14.0	15.2	28.6	29.6	29.8	—	—	—	23.4	—
Doughball time, min	264	264	120	182	180	—	—	—	202	—
Protein, %	11.7	11.6	11.7	9.7	10.0	—	—	—	10.9	—
1935 Irrigated Composite†										
Pearled off, %	25.4	25.2	31.7	32.3	36.6	35.5	35.5	35.5	30.2	32.2
Particle size index	13.8	13.6	25.0	23.2	24.0	26.0	24.8	26.0	19.9	22.1
Doughball time, min	233	92	36	40	38	35	30	32	88	67
Protein, %	10.6	10.2	11.3	9.2	9.4	10.8	10.5	9.2	10.1	10.2
1937 Aberdeen, Idaho										
Pearled off, %	24.1	25.3	35.3	35.5	35.1	37.4	38.2	40.1	31.1	33.9
Particle size index	18.6	15.8	26.4	27.6	25.6	31.6	32.2	34.0	22.8	26.5
Doughball time, min	161	76	31	36	41	30	23	26	69	53
Protein, %	10.3	9.8	10.3	8.5	8.9	9.9	8.4	8.2	9.6	9.3

1937 Bozeman, Mont.										
Pearled off, %	27.5	28.1	34.7	36.5	35.8	35.4	35.3	37.4	32.5	33.8
Particle size index	16.4	20.0	25.0	32.2	28.6	30.8	35.8	34.0	24.4	27.9
Doughball time, min	173	88	33	36	31	33	27	30	72	56
Protein, %	12.4	9.5	11.0	8.2	8.2	9.4	7.9	8.2	9.9	9.4
1938 Composite‡										
Pearled off, %	20.1	21.2	27.9	30.5	27.1	—	—	—	25.4	—
Particle size index	13.6	15.6	24.8	28.4	27.8	—	—	—	22.0	—
Doughball time, min	240	178	42	85	59	—	—	—	121	—
Protein, %	11.6	10.6	11.3	9.1	9.3	—	—	—	10.4	—
Average 3 Samples										
Pearled off, %	25.7	26.2	33.9	34.8	35.8	36.1	36.3	37.7	31.3	33.3
Particle size index	16.3	16.5	25.5	27.7	26.1	29.5	30.9	31.3	22.4	25.5
Doughball time, min	189	85.3	33.3	37.3	36.7	32.7	26.7	29.3	76.3	58.8
Protein, %	11.1	9.8	10.9	8.6	8.8	10.0	8.9	8.5	9.8	9.6
Average 5 Samples										
Pearled off, %	23.9	25.2	33.2	34.3	34.6	—	—	—	30.2	—
Particle size index	15.3	16.0	26.0	28.2	27.2	—	—	—	22.5	—
Doughball time, min	214.2	139.6	52.4	75.8	69.8	—	—	—	110.4	—
Protein, %	11.3	10.3	11.1	8.9	9.2	—	—	—	10.2	—

*Composite of grain from Pendleton and Union, Ore.; Pullman, Wash.; and Sandpoint, Idaho.
†Composite of grain from Aberdeen, Idaho; Bozeman, Mont.; and Logan, Utah
‡Composite of grain from Pendleton, Ore., Mesa, Ariz., Pullman and Lind, Wash., Aberdeen, Idaho, and Bozeman, Mont.

The percentage pearled off, particle size index, and doughball time were determined for several samples of spring and winter wheat grown in the western United States in connection with other studies of quality characteristics of these varieties. The data are given in Table 4 for spring wheat and in Table 5 for winter wheat. The pertinent results are presented graphically in Figs. 2 and 3. Data from dry land and from irrigated stations are included. In some cases the data are for grain from individual stations and in others for composite samples made up of grain from several stations. The protein content of each lot is included for comparison. The varieties, it will be noted, range from typical hard spring and hard winter varieties, such as Marquis and Kharkof, to the very soft common white and club wheats, such as Irwin Dicklow and Albit.

TABLE 5.—*Percentage of grain pearled off, particle size index, doughball time, and percentage of protein for samples of winter wheat varieties grown in the western states.*

Item	Kharkof	Ridit	Triplet	Hybrid 128	Albit	Golden	Rex	Av. of 7 varieties
				1935 Composite*				
Pearled off, %	28.2	30.5	33.8	33.8	33.5	34.0	36.3	32.9
Particle size index	14.6	15.6	24.0	22.2	28.0	26.8	28.4	22.8
Doughball time, min	110	117	102	27	48	37	140	83.0
Protein, %	9.6	9.9	9.1	8.5	8.9	8.4	8.6	9.0
				1937 Composite†				
Pearled off, %	24.3	22.7	29.4	31.7	31.2	30.8	35.0	29.3
Particle size index	15.2	14.2	26.2	23.2	23.6	22.8	29.2	22.1
Doughball time, min	71	73	48	29	35	35	117	58.3
Protein, %	12.1	8.7	11.0	12.0	11.3	11.5	11.7	11.2
				1938 Composite‡				
Pearled off, %	19.0	19.2	25.5	26.4	27.2	27.8	34.7	25.7
Particle size index	13.2	12.8	20.6	19.4	21.6	24.2	27.8	19.9
Doughball time, min	93	83	53	33	35	32	106	62.1
Protein, %	10.1	11.0	9.3	10.1	9.8	9.9	9.1	9.9
				Average 3 Samples				
Pearled off, %	23.8	24.1	29.6	30.6	30.6	30.9	35.3	29.3
Particle size index	14.3	14.2	23.6	21.6	24.4	24.6	28.5	21.6
Doughball time, min	91.3	91.0	67.7	29.7	39.3	34.7	121.0	67.8
Protein, %	10.6	9.9	9.8	10.2	10.0	9.9	9.8	10.0

*Composite of grain from Pendleton and Union, Ore., and Pullman, Wash.
†Composite of grain from Pendleton, Ore., and Pullman, Wash.
‡Composite of grain from Pendleton and Union, Ore.; Pullman, Wash.; and Moscow and Sandpoint, Idaho.

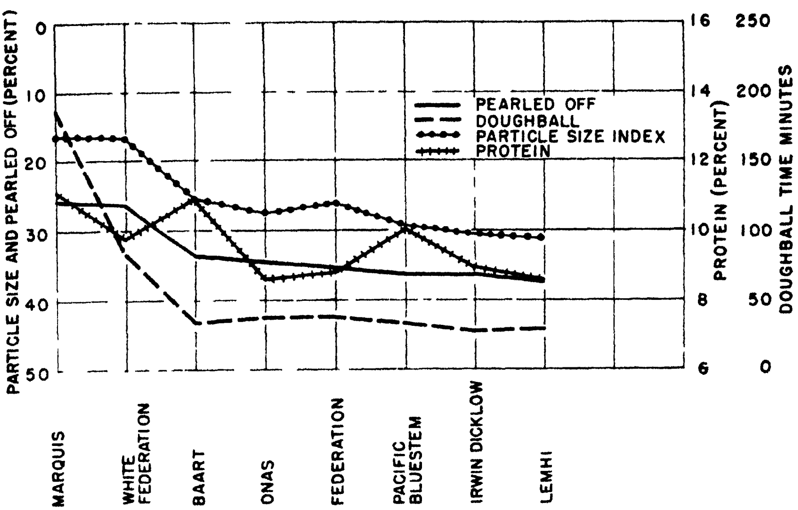

FIG. 2 Percentage of kernel pearled off, particle size index, doughball time, and percentage of protein in three lots of eight varieties of spring wheat

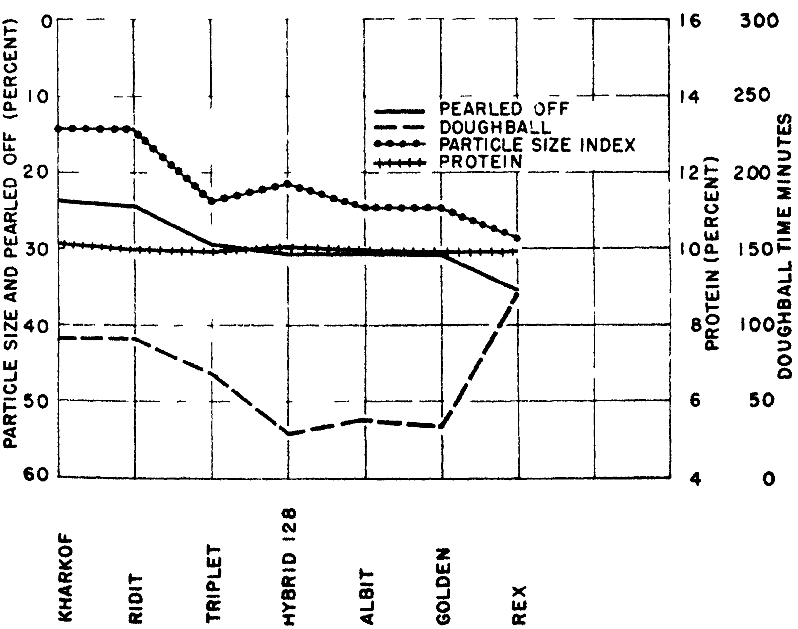

FIG. 3.—Percentage of kernel pearled off, particle size index, doughball time, and percentage of protein in three lots of seven varieties of winter wheat.

The agreement between the percentage pearled off and the particle size index is very good as may be seen by examining the data for individual tests in Tables 4 and 5 or for the averages in Figs. 2 and 3. The large differences in size and shape of the kernels of these varieties might be expected to affect the pearling results and, therefore, disturb the relationship between the percentage pearled off and particle size index, but such apparently was not the case.

The percentage pearled off and the doughball time also show fair agreement for most varieties. A striking exception to this is the winter variety Rex which pearled easiest, yet had the longest doughball time in each of three sets of samples (Fig. 3). The pearling test and index of particle size also show only a slight difference between the spring wheats Marquis and White Federation, while a decided difference was shown in doughball time.

There appears to be only a slight relationship, if any, between the percentage pearled off and the protein content or between the particle size index and the protein content for either the winter or spring varieties.

SUMMARY

A simple pearling test for measuring the hardness of wheat kernels is described. The test is economical with respect to equipment, time, and quantity of grain.

The results are consistent with what is known regarding the relative hardness of different varieties and very high interstation correlations were obtained.

High correlation coefficients were found between the percentage of the kernels pearled off and the particle size index.

Only slightly lower negative correlation coefficients were obtained between the percentage of kernels pearled off and the doughball time. Certain varieties, however, reacted quite differently to the two tests.

Little correlation was found between the percentage pearled off, particle size index, doughball time, and protein content of the grain of the varieties studied.

GROWTH HABIT OF SOME WINTER WHEAT VARIETIES AND ITS RELATION TO WINTERHARDINESS AND EARLINESS[1]

K. S. QUISENBERRY AND B. B. BAYLES[2]

WHEAT varieties have been grouped into three general classes, namely, winter, intermediate, and spring, based on their habit of growth. Actually, as has been pointed out by Percival; Clark, Martin, and Ball; and Bayles and Martin,[3] and others, there is a continuous series of varieties or strains from those having very early spring growth habit to those with an extreme degree of winter habit. Thus, within the varieties commonly classed as winter, there are different degrees of winterness. Numerous papers have reported the growth habit of wheat varieties at individual stations for one or more years, but the authors have not seen publications giving data on the growth habit of the same varieties grown under widely different environmental conditions. In order to study this problem, several varieties were seeded in the spring at eight experiment stations and their relative degree of winterness determined. The relation between growth habit, winterhardiness, and time of heading from fall seeding will also be discussed.

Nineteen varieties of wheat classified as having winter habit, one with intermediate habit, and one with spring habit of growth were seeded on three dates in the spring of 1934, 1935, and 1936 at each experiment station Seven other varieties having winter habit of growth were grown for 1 or 2 years. The name, latitude, and longitude of each station are given in Table 1. The average critical seeding date after which Harvest Queen, Karmont, Minhardi, Denton, Red Rock, and Odessa did not produce heads the same year from at least 5 to 10% of the culms is also given, together with the deviations from this date for each station as compared with Denton, Tex., and also the calculated deviations based on Hopkins' bioclimatic law.[4] These six varieties were chosen because, from the data obtained, it was possible to establish the critical date more accurately. The critical date for seeding the above-mentioned varieties at Denton, Tex., was January 29, whereas at Pullman, Wash., it was March 25, or 55 days later. The critical dates for the other stations were between these two.

According to Hopkins' law, biological phenomena controlled by seasonal changes such as heading dates of wheat should take place in the spring 4 days later for each degree of latitude, 4 days earlier for each 5° of longitude from east to west, and 1 day later for each in-

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication June 26, 1939.

[2]Agronomists.

[3]PERCIVAL, J. The wheat plant; a monograph. London: 463 pages, illus. 1921.
CLARK, J. A., MARTIN, J. H., and BALL, C. R. Classification of American wheat varieties. U. S. D. A. Bul. 1074. 1922.
BAYLES, B. B., and MARTIN, J. F. Growth habit and yield in wheat as influenced by time of seeding. Jour. Agr. Res., 42:483–500. 1931.

[4]HOPKINS, A. D. Bioclimatics. U. S. D. A. Misc. Pub. 280. 1938.

TABLE 1.—*Critical date of seeding for certain varieties of wheat, the calculated date based on Hopkins' law, and the latitude, longitude, and altitude of the stations where the varieties were grown.*

Station	Latitude	Longitude	Altitude, feet	Critical date of seeding	Deviation from Denton, Tex.	
					Actual date	Hopkins' law
Denton, Tex	33°10′	97°10′	600	Jan. 29	0	0
Tucson, Ariz ...	32°13′	110°56′	2,400	Jan. 28	-1	3
Woodward, Okla	36°27′	99°33′	2,002	Feb. 7	9	25
Manhattan, Kans.	39°10′	96°33′	1,100	Feb. 17	19	30
Lincoln, Nebr	40°49′	95°45′	1,180	Feb. 19	21	37
Pendleton, Ore...	45°38′	118°44′	1,100	Mar. 14	44	37
Akron, Colo ...	40°	103°	4,560	Mar. 15	45	62
Pullman, Wash...	46°48′	117°6′	2,532	Mar. 25	55	57

crease of 100 feet in altitude. The actual and calculated critical dates agree fairly well at some stations while at other stations they differ considerably. For example, at Akron, Colo., the observed critical date was 45 days later than at Denton, Tex., while according to Hopkins' law it should be 62 days later. An examination of temperature records showed that the months of February, March, and April averaged 0.4° above normal at Denton and 1° above normal at Akron, for the years during which observations were made, *viz.*, 1934, 1935, and 1936. At all stations except Pendleton and Tucson, the critical date as determined by field plantings was earlier than that determined by Hopkins' bioclimatic law.

The date first headed (when about one-tenth of the heads were emerged) was recorded for each variety for each of three seeding dates in the spring in 1934, 1935, and 1936 at each station. When a variety did not head normally the percentage of the heads that emerged was usually recorded. The results from Pullman, Wash., in 1936 are given in Table 2. Based on data similar to these for each year at each station, the varieties were ranked for degree of winterness. The 3-year average rankings for each station are given in Table 3. Data from other experiments on winter survival and date of heading from fall seeding are also included.

Under the wide range of environmental conditions represented at the eight stations, it might be expected that the ranking of the varieties for degree of winterness would be different. As shown in Table 3, such was not the case as the varieties rank in about the same order for degree of winterness as indicated by the habit of growth at each station.

The relations between average degree of winterness, winter hardiness, and date of heading from fall seeding are shown in Fig. 1. It is interesting to note that date of heading from fall seeding and winterhardiness of the winter varieties are not necessarily related to the degree of winterness. Nebraska No. 60 is more hardy and later in heading from fall seeding than Kharkof, yet can be seeded later in the spring than varieties such as Blackhull and Quivira and still produce normal heads. On the other hand, Red Rock ranks next to

TABLE 2.—*Date of heading and maturity for wheat varieties sown on three dates in the spring of 1936 at Pullman, Wash.*

Variety	C. I. No.	Seeded March 4, emerged April 14: 10% headed	50% headed	50% ripe	Seeded March 19, emerged April 15: 10% headed	50% headed	50% ripe	Seeded April 15, emerged April 20: 10% headed	50% headed	50% ripe
Ceres	6900	June 10	June 11	July 19	June 12	June 13	July 21	June 14	June 15	July 28
Purplestraw	1915	June 13	June 15	July 26	June 19	June 21	July 29	June 28	July 2	Aug 10
Nebraska No. 60	6250	June 19	June 21	July 26	June 25	June 27	July 31	Aug 19	Aug 29	—
Early Blackhull	8856	June 14	June 15	July 25	June 25	June 28	Aug 1	Aug 20	Aug 29	—
Utah Kanred	11608	June 19	June 21	July 27	June 26	June 28	Aug 5	Aug 20	Aug 29	—
Turkey selection	7366	June 19	June 21	July 28	June 26	June 28	Aug 5	Aug 30	—	—
Relief	10082	June 19	June 21	July 28	June 26	June 29	Aug 7	—	—	—
Tenmarq	6936	June 20	June 21	July 28	July 2	July 7	Aug 10	Aug 29	—	—
Turkey selection	10016	June 17	June 19	July 26	July 2	July 6	Aug 10	—	—	—
Kanred	5146	June 20	June 22	July 28	July 3	July 7	Aug 10	—	—	—
Quivira	8886	June 19	June 21	July 27	July 6	July 11	Aug 12	—	—	—
Kharkof	1442	June 22	June 24	July 28	July 6	July 11	Aug 15	—	—	—
Kanred Hard Federation	10092	June 16	June 18	July 26	July 7	July 13	Aug 23	—	—	—
Blackhull	6251	June 21	June 22	July 28	July 12	July 19	Aug 20	—	—	—
Minturki	6155	June 22	June 24	Aug 1	July 14	July 20	Aug 25	—	—	—
Turkey	1558	June 22	June 24	July 29	July 14	July 20	Aug 31	—	—	—
Cheyenne	8885	June 25	June 28	July 28	July 20	July 29	Sept 8	—	—	—
Karmont	6700	June 25	June 27	July 30	July 16	Aug 2	—	—	—	—
Denton	8265	June 28	July 3	Aug 5	July 18	Aug 6	—	—	—	—
Harvest Queen	6199	June 23	June 27	Aug 6	July 19	Aug 6	—	—	—	—
Yogo	8033	June 25	June 29	July 30	July 29	Aug 20	—	—	—	—
Minhardi	5149	June 26	July 3	Aug 12	Aug 12	Aug 20	Sept 5	—	—	—
Kawvale	8180	July 1	July 7	Aug 10	Aug 8	Aug 29	—	—	—	—
Lutescens 0329	8896	July 8	July 13	Aug 15	Aug 6	—	—	—	—	—
Odessa	4475	July 7	July 11	Aug 14	Aug 8	—	—	—	—	—
Red Rock	5597	July 30	Aug 8	—	—	—	—	—	—	—

TABLE 3.—*Ranking for degree of winterness of 28 wheat varieties together with data for winter survival and date of heading from normal fall seeding at eight stations.*

Variety or cross	C. I. No.	3-year average ranking for degree of winterness when grown at									Winter survival in percentage of Kharkof*	Date headed†
		Tucson, Ariz.	Denton, Tex.	Manhattan, Kans.	Woodward, Okla.	Lincoln, Nebr.	Akron, Colo.	Pendleton, Ore.	Pullman, Wash.	Average		May
Ceres	6900	1	1	1	1	1	1	1	1	1.0	—	—
Purplestraw	1915	2	2	2	2	2	2	2	2	2.0	—	—
Early Blackhull	8856	4	3	3	4	4	3	3	3	3.4	70.9	17
Utah Kanred‡	11608	3	4	4	3	3	4	4	6	3.9	—	28
Relief§	10082	5	5	5	5	6	5	5	7	5.4	82.1	26
Kanred-Hard Federation	10092	6	8	7	7	7	7	6	8	7.0	89.8	21
Nebraska No. 60	6250	8	7	11	8	12	8	7	5	8.3	107.1	28
Turkey selection	7366	10	12	12	6	5	6	11	4	8.3	75.5	—
Quivira	8886	9	6	8	9	8	9	9	9	8.4	82.6	22
Blackhull	6251	7	9	9	10	10	10	8	10	9.2	78.6	23
Tenmarq	6936	12	11	6	11	11	11	12	11	10.6	83.2	24
Kanred	5146	13	10	13	12	13	12	10	12	11.9	102.9	26
Turkey selection	10016	11	14	10	13	9	13	13	13	12.0	105.9	—
Minturki	6155	14	13	14	15	14	15	15	15	14.4	117.7	27
Kharkof	1442	15	15	16	17	15	16	14	14	15.3	100.0	27
Turkey	1558	17	17	19	14	18	14	16	16	16.4	—	27
Cheyenne	8885	18	16	18	16	17	18	18	17	17.3	102.9	27
Yogo‡	8033	19	18	17	20	16	17	17	19	17.9	119.2	29
Harvest Queen	6199	16	20	15	21	19	20	19	20	18.8	87.4	29
Karmont	6700	23	21	20	19	20	19	20	18	20.0	99.3	28
Minhardi	5149	20	23	21	18	22	25	22	21	21.5	124.1	28
Denton	8265	21	19	22	22	24	21	21	22	21.5	—	27
Kawvale§	8180	22	24	23	23	25	22	24	23	23.3	93.5	26
Red Rock	5597	24	22	25	26	23	23	26	25	24.3	70.0	27
Lutescens 0329‡	8896	25	25	24	24	26	24	25	24	24.6	134.0	—
Odessa	4475	26	26	26	25	21	26	23	26	24.9	117.0	30
Don§	7633	—	—	—	—	27	—	—	27	—	—	—
Durable§	8860	—	—	—	—	27	—	—	28	—	—	—

*For survival data for Red Rock, see Cereal Chem., 16: 208–223, 1939; for Relief and Turkey selection (C. I. 7366), see results from cooperative wheat varietal experiments in the Western Region in 1932 and 1933, respectively, U.S.D.A., B.P.I., Div. C. C. and D. Mimeo. Pubs. 1933 and 1934; for all other varieties, see U. S. D. A. Circs. 378, 1926, and 141, 1930, and Jour. Amer. Soc. Agron., 30: 399–405, 1938.

†Average for fall seeding at Pendleton, Ore., in 1933 and 1934, and at Lincoln, Nebr., in 1937.

‡Degree of winterness rating based on 2 years' results.

§Degree of winterness rating based on 1 year's results.

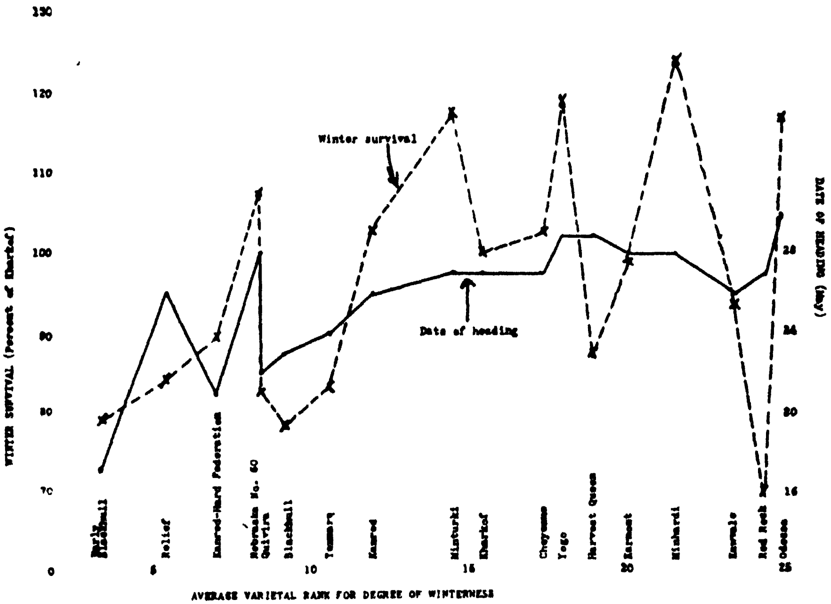

FIG. 1.—Relation between degree of winterness from spring seeding and winterhardness from fall seeding and between degree of winterness from spring seeding and date of heading from fall seeding of several winter wheat varieties.

Odessa in degree of winterness but is no more hardy than Early Blackhull and is earlier in heading from fall seeding than Nebraska No. 60.

Several of the varieties (Early Blackhull, Kanred-Hard Federation, Quivira, Tenmarq, and Blackhull) included in this study are early maturing and are able to produce heads from later spring seeding than varieties such as Kharkof, but none of these early maturing varieties approach Kharkof in hardiness.

SUMMARY

Growth habit as determined from spring seedings of 28 wheat varieties was studied at eight experiment stations in the years 1934 to 1936, inclusive. Data on earliness from fall sowing and winter survival from other tests are included in order to study their relation with the degree of winterness.

The varieties rank in about the same order for degree of winterness when grown at each of the stations.

Degree of winterness is not closely related to time of heading from fall seeding or to winterhardiness in the varieties studied.

None of the early varieties were as hardy as most of the late ones. However, a few of the late varieties were no more hardy than earlier maturing ones.

THE EFFECT OF HEIGHT AND FREQUENCY OF CUTTING ALFALFA UPON CONSEQUENT TOP GROWTH AND ROOT DEVELOPMENT[1]

S. C. HILDEBRAND AND C. M. HARRISON[2]

THE increased acreage of alfalfa in the north central section of the United States, particularly in Michigan, is partially due to its use as a pasture crop during the hot summer months of July and August. During this period conditions of low rainfall and high temperatures usually prevail and native bluegrass pastures are largely dry and dormant. Experiments conducted at the Michigan Agricultural Experiment Station at East Lansing show that alfalfa or a mixture of alfalfa and smooth brome grass, because of the drought resistance of these plants, will furnish more green feed during the hot months than any other combination of perennial plants yet tried. Alfalfa has proved to be highly productive, palatable, nutritious, and reasonably enduring provided proper management practices are followed

Research has shown that cutting at immature stages of growth may result not only in damage to the stand, but also in a reduction of the amount of new growth produced. Graber, et al. (2)[3] found that frequent cutting of alfalfa at immature stages of growth lowered the productivity and vigor of the plants, favored weed encroachment, and accelerated both winter and summer damage to the stand, all of which was primarily the result of depleted food reserves in the roots.

Albert (1), Willard (6), Nelson (4), and Kiesselbach and Anderson (3) substantiate the findings of Graber. Experiments have also shown that alfalfa should be pastured at a higher level than is generally practiced on pasture plants in order to secure the best yields and allow for adequate storage of food reserves in the roots.

With the above facts in view the experiment described here was set up in the greenhouse at East Lansing, Mich., to study the effect of the height and frequency of cutting alfalfa upon the production of "recovery" growth and root development, and to obtain an indication as to the proper height-level of grazing alfalfa for maximum production of feed and maintenance of the stand.

EXPERIMENTAL PROCEDURE

In September, 1937, several hundred Hardigan alfalfa plants were dug from a 1-year-old alfalfa field. These plants were brought into the greenhouse, selected for uniformity, and transplanted into sand cultures in 10-inch clay pots, eight plants per pot. They were kept growing until April, 1938, by frequent watering and the application of a complete nutrient solution at regular intervals.

On April 13 the cultures were selected at random and arranged in five sets of nine each, to be cut back to 1, 3, 6, 9, and 12 inches, respectively. Three of each of the sets of nine were cut at weekly, three at biweekly, and three at monthly

[1]Contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Jour. Article 368 (N. S.). Received for publication July 3, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 799.

intervals. In addition, nine cultures were selected as final checks and three selected as representative of the group to show the condition of the plants at the beginning of the experiment.

Beginning on April 13, the plants were cut for a period of 12 successive weeks at their respective height levels and intervals, the checks being left uncut. At the end of the 12 weeks all plants, including the checks, were completely defoliated once each week for four successive weeks in an attempt to measure root storage by the amount of recovery growth made between defoliations. The cultures were then allowed to recover for two weeks and the sand washed from the roots. Green and dry weights were taken from each cutting and for the tops and roots at the end of the experiment.

RESULTS

The tops and roots of these three representative cultures were separated and the green and dry weights recorded in Table 1 (See Fig 1.)

TABLE 1. *The yield of tops and roots of alfalfa plants before cutting treatments were begun*

Culture No	Tops		Roots	
	Green weight, grams	Dry weight, grams	Green weight, grams	Dry weight, grams
1	120 00	35 00	116.70	27.45
2	121 00	27.50	90 80	26.45
3	115.00	27.00	128 45	28.40
Mean weight, grams	118 67	29 17	111 98	27 43

EXPERIMENT 1 YIELD OF TOP GROWTH

The comparable effect of cutting alfalfa back to 1, 3, 6, 9, and 12 inches from the sand upon the yield of top growth is shown in Tables 2, 3, and 4 for weekly, biweekly, and monthly cutting intervals, respectively

More top growth was produced at first when the plants were cut at 1- and 3-inch levels (Table 2), but after several cuttings were made the reverse was true. The alfalfa plants which were cut to low levels made an upright growth, while the plants cut to the 9- and 12-inch levels made a large portion of their growth from the crown but produced little growth above the cutting level.

Plants cut at the 6-inch level. produced the most "recovery" growth, but the yields were not significantly greater than those cut at the 3-, 9-, or 12-inch levels. Cutting at the 1-inch level, however, gave significantly lower yields than any of the other treatments.

Differences in total yield between the high and low levels of cutting were large (Table 3). The amount of "recovery" growth was significantly larger when the alfalfa was cut at a 6-inch level than when cut at 1-, 3-, or 12-inch levels.

FIG 1 —Alfalfa cultures at the beginning of the experiment, April 13, 1938. *Above*, representative cultures used in the experiment. *Below*, the same cultures after washing sand from the roots.

TABLE 2.—*The effect of weekly cuttings at various heights upon the dry matter yield of tops of alfalfa, average of three cultures except for checks.**

Date of cutting, 1938	Dry matter in grams when cut at					Av. of nine checks, grams
	1 inch	3 inches	6 inches	9 inches	12 inches	
April 13	17.00	19.00	13.33	9.00	5.17	
April 20	1.26	1.64	0.93	0.51	0.39	
April 27	1.34	2.45	1.93	0.60	0.44	
May 4	1.42	2.53	1.96	1.39	0.87	
May 11	0.68	1.30	1.81	1.00	1.20	
May 18	0.64	0.77	1.40	1.43	1.39	
May 25	1.05	1.69	2.45	2.23	2.23	
June 1	0.72	1.75	2.29	2.13	1.64	
June 8	0.64	2.53	3.28	3.26	1.70	
June 15	0.37	3.18	3.69	3.51	4.70	
June 22	0.51	2.86	2.57	1.78	2.35	
June 29	0.47	3.97	5.00	3.87	5.01	
July 6†	2.94	19.40	37.50	54.30	72.50	79.53
Total yield	29.03	63.07	78.14	85.01	99.59	79.53
"Recovery" growth made above the cutting level‡	9.10	24.67	27.31	21.71	21.92	

*The yield at each cutting date represents the average yield of tops from all of the three cultures under each treatment. The differences required for significance were calculated by use of an analysis of variance (5). This statement also applies to Tables 3, 4, 5, 6, 7, and 8.

†All of the cultures were completely defoliated on this date.

‡Yields on April 13 and July 6 were disregarded in securing "recovery" growth. On April 13 the plants were first cut down to their respective height levels and on July 6 the plants were completely defoliated. No yields of tops above the cutting level were taken on July 6. Yield differences required for significance between amounts of "recovery" growth: Odds of 19:1 = 11.01 grams; odds of 99:1 = 16.01 grams.

TABLE 3.—*The effect of biweekly cuttings at various heights upon the dry matter yield of tops of alfalfa, average of three cultures except for checks.*

Date of cutting, 1938	Dry matter in grams when cut at					Av. of nine checks, grams
	1 inch	3 inches	6 inches	9 inches	12 inches	
April 13	19.00	17.50	14.00	9.17	4.07	
April 27	5.06	3.56	4.03	2.82	1.36	
May 11	3.35	4.03	4.60	3.75	3.81	
May 25	3.00	2.77	3.97	3.81	3.22	
June 8	3.71	6.20	8.03	7.48	5.54	
June 22	3.10	5.83	7.73	5.37	6.83	
July 6*	8.17	24.53	48.83	63.93	77.57	79.53
Total yield	45.39	64.42	91.19	96.33	102.40	79.53
"Recovery" growth made above the cutting level†	18.22	22.39	28.36	23.23	20.76	

*All cultures were completely defoliated on this date.

†Yields on April 13 and July 6 disregarded in securing "recovery" growth. On April 13 the plants were first cut down to their respective height levels and on July 6 the plants were completely defoliated. No yield of tops above the cutting level taken. Yield differences required for significance between amounts of "recovery" growth: Odds of 19:1 = 5.28 grams; odds of 99:1 = 7.68 grams.

When cut at monthly intervals more "recovery" growth was obtained at the 1-inch than at any of the higher levels of cutting (Table

TABLE 4.—*The effect of monthly cuttings at various heights upon the dry matter yield of tops of alfalfa, average of three cultures except for checks.*

Date of cutting, 1938	Dry matter in grams when cut at					Av. of nine checks, grams
	1 inch	3 inches	6 inches	9 inches	12 inches	
April 13	23.17	18.83	13.67	10.67	3.37	
May 11	15.27	12.87	15.37	10.50	2.50	
June 8	13.80	14.23	11.07	14.75	9.50	
July 6*	26.67	37.80	59.67	77.27	69.07	79.53
Total yield	78.91	83.73	99.78	113.19	84.44	79.53
"Recovery" growth made above the cutting level†	29.07	27.10	26.44	25.25	12.00	

*All cultures were completely defoliated on this date.

†Yields on April 13 and July 6 disregarded in securing "recovery" growth. On April 13 the plants were first cut down to their respective height levels and on July 6 the plants were completely defoliated. No yield of tops above the cutting level taken. Yield differences required for significance between amounts of "recovery" growth: Odds of 19:1 = 13.47 grams, odds of 99:1 = 19.6 grams.

4) The alfalfa cut at the 12-inch level gave significantly lower yields than that cut at the 1-, 3-, or 6-inch levels, due to the maturity of the plants and the lack of vegetative growth.

TABLE 5.—*Summary of the effect of height and interval of cutting upon the "recovery" growth of alfalfa in grams dry weight, Tables 2, 3, and 4 corrected to 8 weeks' treatment, average of three cultures.**

Interval of cutting	Dry matter in grams when cut at				
	1 inch	3 inches	6 inches	9 inches	12 inches
Weekly	7.75	14.66	16.05	12.55	9.86
Biweekly	15.12	16.56	20.63	17.86	13.93
Monthly	29.07	27.10	26.44	25.25	12.00

*Yield differences required for significance between amounts of "recovery" growth: Odds of 19:1 = 8.61 grams, odds of 99:1 = 11.66 grams.

In order to compare the recovery yields obtained under each cutting interval over a comparable growing period, only those yields for the eight weeks' period April 13 to June 8 are given in Table 5. The amount of "recovery" growth increased as the time interval of cutting increased with the exception of the cultures cut at 12 inches (Table 5). Not all of these increases were significant. The weekly cuttings gave significantly lower yields than the monthly cuttings except for the plants cut at the 12-inch level. At the 1- and 3-inch cutting levels, significantly lower yields were obtained from biweekly over monthly cuttings.

EXPERIMENT II. FOOD RESERVES IN THE ROOTS

To determine the food storage in the roots of alfalfa, the plants in each culture were completely defoliated and the stored food was measured in terms of new top growth produced. At the end of the experiment the dry weight of the roots from each culture was determined.

The cultures which were previously cut for 12 weeks at various heights and intervals were completely defoliated each week for four successive weeks. Yields were taken and are recorded in Table 6.

TABLE 6.—*Growth dry weight in grams made in weekly periods following complete defoliation, average of three cultures except for checks.*

Date of defoliation	Dry weight in grams when cut at 1 inch	3 inches	6 inches	9 inches	12 inches	Av. of nine checks, grams
	Previous Cuttings Made Weekly					
July 13	0.16	1.12	1.82	2.56	3.36	3.69
July 20	0.01	1.33	2.12	3.93	6.13	5.59
July 27	dead	0.69	1.20	2.70	4.07	5.24
Aug. 3	dead	0.33	0.49	1.64	1.90	4.07
Total		3.47	5.63	10.83	15.66	18.59
	Previous Cuttings Made Biweekly					
July 13	0.32	0.91	1.58	2.07	2.12	3.69
July 20	0.26	1.55	2.03	4.00	4.63	5.59
July 27	0.03	0.88	1.60	2.93	4.00	5.24
Aug. 3	dead	0.58	0.86	1.61	2.35	4.07
Total		3.92	6.07	10.61	13.10	18.59
	Previous Cuttings Made Monthly					
July 13	1.36	1.56	1.62	3.23	3.23	3.69
July 20	1.81	2.76	3.40	4.57	5.57	5.59
July 27	0.92	1.73	1.87	3.77	3.70	5.24
Aug. 3	0.49	0.91	1.18	1.73	2.37	4.07
Total*	4.58	6.96	8.07	13.30	14.87	18.59

*Totals are not given for the 1-inch cultures cut weekly and biweekly because the plants died before four complete defoliations were made. The plants being dead, yields from these cultures were not included in the analysis of variance. Yield differences required for significance between total amounts of recovery growth: Odds of 19:1—5.92 grams; odds of 99:1—8.01 grams.

As the height level of the previous cutting increased, the yield of tops, following complete defoliation, increased. This holds true for weekly, biweekly, and monthly cutting intervals. Alfalfa cut at the 1-inch level in both the weekly and biweekly cutting intervals died before four complete defoliations were made. Plants cut at the 1- and 3-inch levels, under each time interval gave significantly lower yields than the plants cut at the 9- and 12-inch levels or the check cultures.

Following four weekly complete defoliations the plants were allowed to recover for two weeks and the sand washed from the roots. The tops and roots were separated and dry weights recorded in Tables 7 and 8, respectively.

The condition of the tops and roots of the plants after being subjected to the various cutting treatments is shown in Figs. 2, 3, and 4 for weekly, biweekly, and monthly cutting intervals, respectively.

TABLE 7.—*Dry weight of tops of alfalfa after being allowed to recover for two weeks after four weekly complete defoliations, average of three cultures except for checks.**

Previous interval of cutting	Dry weight in grams at previous height of cutting of					Av. of nine checks, grams
	1 inch	3 inches	6 inches	9 inches	12 inches	
Weekly.	Dead	0.97	0.37	6.00	11.23	13.47
Biweekly	Dead	2.77	1.98	6.30	9.47	—
Monthly.	1.17	3.13	3.87	10.27	9.67	—

*Yield differences required for significance between amounts of recovery growth Odds of 19:1 = 5.61 grams; odds of 99:1 = 7.60 grams

FIG. 2.—Growth response and condition of roots of plants cut at weekly intervals, August 16, 1938. *Above*, growth response after two weeks following four successive complete defoliations of cultures cut back weekly over a period of 12 weeks to the indicated heights. *Below*, the same as above after washing sand from the roots. Reading left to right: Check, 12-inch, 9-inch, 6-inch, 3-inch, and 1-inch levels of cutting. Note the lack of root development of the plants cut at the 1-, 3-, and 6-inch levels along with the dead roots present. The 9- and 12-inch cutting levels and the check cultures have a good healthy root system, although that of the plants cut at the 9-inch level is decidedly smaller than those of the other two.

DISCUSSION

Carbohydrate food storage in the roots of alfalfa plants depends primarily upon top growth. As carbohydrate materials are manufactured through photosynthesis they are either utilized by the growing plant in producing new plant parts or stored for future use. As

TABLE 8.—*Dry weight of alfalfa roots at the end of the experiment, average of three cultures except for checks.**

Previous interval of cutting	Dry weight in grams with height level of cutting prior to complete defoliation					Av. of nine checks, grams
	1 inch	3 inches	6 inches	9 inches	12 inches	
Weekly	3.22	8.76	11.46	22.31	39.39	—
Biweekly	5.21	13.21	17.14	24.16	30.64	—
Monthly	11.09	18.24	20.00	33.79	38:88	—
						41.52

*Yield differences required for significance between weight of roots: Odds of 19:1 = 11.03 grams; odds of 99:1 = 14.93 grams.

FIG. 3.—Growth response and condition of roots of plants cut at biweekly intervals, Aug. 16, 1938. *Above*, growth response after two weeks following four successive complete defoliations of cultures cut back biweekly over a period of 12 weeks to the indicated height. *Below*, the same as above after washing sand from the roots. Reading left to right: Check, 12-inch, 9-inch, 6-inch, 3-inch, and 1-inch levels of cutting. Note the lack of response of the plants cut at the 1-inch level as compared with those cut at the 3-inch level. Those cut at 6- and 9-inch levels show medium response, but are not comparable to the 12-inch level or check. The same general statement holds true for the roots.

alfalfa plants mature, growth processes slow up and more materials are manufactured than needed, the surplus being stored principally in the roots.

Alfalfa plants with a small amount of leaf tissue will develop only a small root system. It is evident that not as much total food can be stored in a small root as in a large one. If the top growth is com-

pletely removed, carbohydrate manufacture stops, hence any new growth initiated must be at the expense of reserves. If the tops are removed frequently, allowing for little or no food storage, the reserves will soon become depleted to such an extent that no new growth will be initiated and as a result the plant becomes weakened and dies.

FIG. 4.—Growth response and condition of roots of plants cut at monthly intervals, Aug. 16, 1938. *Above*, growth response after two weeks following four successive complete defoliations of cultures cut back monthly over a period of 12 weeks to the indicated height. *Below*, the same as above after washing sand from the roots. Reading left to right: Check, 12-inch, 9-inch, 6-inch, 3-inch, and 1-inch levels of cutting. Small responses were made by the alfalfa cut at the 1-, 3-, and 6-inch levels, but they do not compare favorably with that made by the plants cut to higher levels. The same is true for the roots. Note the dead roots of the plants cut at the 1-, 3-, and 6-inch levels, especially those cut at the 1-inch level, as compared with the well-developed root system of the check plant and those cut at the 9- and 12-inch levels.

When alfalfa plants are cut in such a manner that a large portion of the top growth remains, carbohydrate manufacture may continue. After several frequent, successive and complete defoliations plants with large root systems, which contain a large amount of reserve food, continue to initiate new growth. Eventually the reserves of plants treated in this manner will become depleted if close cutting is continued.

Plants cut weekly to 1-inch levels made very little recovery growth following complete defoliation and after two successive defoliations, one week apart, all of the plants were dead. This would indicate that the cutting treatment previous to complete defoliation had allowed very little storage of reserve materials. The plants which were cut

biweekly to 1-inch levels responded in a similar manner but withstood a third defoliation before the plants died, indicating that, although the storage of reserves was low, it was somewhat higher than that of the plants cut weekly The amount of recovery growth following complete defoliation was considerably greater in the plants cut biweekly at the 1-inch level than those cut weekly at the same level. The plants cut to the 1-inch level at monthly intervals not only survived four complete defoliations, but the production of new growth was far greater on any given date than that of the plants previously cut to 1 inch either weekly or biweekly This would indicate that there was a larger amount of storage in plants cut at monthly intervals than those cut at weekly or biweekly intervals. In general, these observations hold true for all of the cultures with the exception of the plants cut at the 12-inch level.

In all cases except the plants cut weekly and biweekly at the 1-inch level, the first defoliation resulted in less production of "recovery" growth in a week than did the second defoliation. After the second defoliation the trend is downward in practically all cases, indicating that the storage supplies were rapidly diminishing.

CONCLUSIONS

1. Cutting alfalfa frequently and close to the crown resulted in depletion of the food reserves in the roots and a marked decrease in yield of hay and vigor of the plants.

2. Alfalfa cut frequently at a high level (12 inches) resulted in decreased yields owing to loss of leaves due to the maturity of the plant and a lack of vegetative growth.

3. Alfalfa remained vigorous when cut back to a 6-inch level either biweekly or monthly. At an interval of one week between cuttings the plants failed to produce sufficient stored food to maintain the plant over unfavorable periods of growth.

4. Cutting back to the 9-inch level gave good yields of top growth and roots when cut at weekly or biweekly intervals, whereas the monthly interval of cutting allowed the plants to mature, resulting in a retardation of vegetative growth.

5. Although cutting at 12 inches resulted in an abundance of food storage, the yield of top growth above the cutting level was relatively low due to the maturing of the tops below the cutting level.

LITERATURE CITED

1. ALBERT, W. B. Studies on the growth of alfalfa and some perennial grasses. Jour. Amer. Soc. Agron., 21:29 34. 1927.
2. GRABER, L. F., LEUKEL, W. A., NELSON, N. T., and ALBERT, W. B. Organic food reserves in relation to the growth of alfalfa and some other perennial herbaceous crops. Wis. Agr. Exp. Sta. Res. Bul. No. 80. 1927.
3. KIESSELBACH, T. A., and ANDERSON, A. Alfalfa investigations. Nebr. Agr. Exp. Sta. Res. Bul. No. 36. 1926.
4. NELSON, N. T. The effects of frequent cutting on the production, root reserves, and behavior of alfalfa. Jour. Amer. Soc. Agron., 17:100–113. 1925.
5. SNEDECOR, G W. Statistical Methods. Ames, Iowa: Collegiate Press. 1937.
6. WILLARD, C. J. Root reserves of alfalfa with special reference to the time of cutting and yield. Jour. Amer. Soc. Agron., 22:595-602. 1930.

SAMPLING INTENSITY IN VEGETATION SURVEYS MADE BY THE SQUARE-FOOT DENSITY METHOD[1]

DAVID F. COSTELLO AND GRAYDON E. KLIPPLE[2]

METHODS of making surveys of range land vegetation have been evolving slowly for a period of more than 30 years. Since the beginning, determination of density or spread of vegetation above the ground has been an integral part of survey procedure. Originally, density was estimated by the system common to the reconnaissance method of range surveying (3).[3] More recently a method of determining density known as the square-foot density or point-observation-plot method has been developed by Stewart and Hutchings (4), and this method is now optional in standard range survey instructions (3). Questions and comments which have arisen as a result of the use of the optional square-foot density method in range surveys have emphasized a need for specific information on sampling intensity as reflected in number of plots required for an estimate within given limits of accuracy.

This paper, based on sample plot data recorded from all major range vegetation types in Colorado, Wyoming, and the Black Hills region of South Dakota, deals with sampling intensity in relation to reliability of mean densities and forage factors secured by the square-foot density method. It also presents the relationships between number of plots required for a reliable sample and (a) size of area sampled, (b) vegetation type, and (c) adequacy of sampling as determined by the purpose of the survey.

SOURCE AND NATURE OF THE DATA

A very considerable mass of data, obtained through the use of the square-foot density method of making range surveys, has been assembled by the Rocky Mountain Forest and Range Experiment Station. Observations on 4,620 plots were obtained in a general survey of range conditions throughout Colorado and Wyoming and in the Black Hills of South Dakota in October 1935. A forage inventory of Colorado and Wyoming, started in the spring of 1936, resulted in observations on 44,123 sample plots by November 1938. These data were supplemented by 24,476 sample plots which were established by various state and federal agencies[4] under careful supervision and coordination during 1936 and 1937.

The basic data on all plots were recorded on Form 764b of the instructions for range surveys (3) or on similar forms. Species were listed by vegetation types and their densities were recorded directly in square feet or fractions thereof for each plot. Plot locations within any type area were determined by throwing a stone into the type to locate the first plot and by stripping or grid-ironing at a predetermined sampling interval until the necessary number of plots was established.

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[1]Contribution from the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. Received for publication July 10, 1939.

[2]Associate Forest Ecologist and Junior Agricultural Economist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 810.

[4]The agencies participating in this cooperative project were the Forest Service, Resettlement Administration, Soil Conservation Service, of the U. S. Dept. of Agriculture; the Division of Grazing of the U. S. Dept. of Interior; Colorado State College of Agriculture and Mechanic Arts; and the University of Wyoming.

For possible future reference, plots were located by section, township, and range and in most instances designated on base maps. Plot data were accompanied by type descriptions and comments on forage utilization, range conditions, class of livestock, and erosion.[5]

METHODS OF ANALYSIS

SORTING OF PLOT DATA

The data from individual plots were grouped by vegetation types or portions of vegetation types within geographic localities, national forests, management units, or some similar area. When excessive numbers of plots were available from a vegetation type within a given area a random sample of 500 to 2,000 plots was chosen for statistical analysis. Plots representing small areas of exceedingly high or low densities within broad types of average density were retained in all instances since they were an expression of type heterogeneity.

In computing the number of plots required for varying degrees of accuracy on large areas, plots were combined without reference to range conditions. For small areas, such as would be represented by management units, problem areas, and sub-ranch units, plot series were sorted into three groups depending on whether or not the range condition was considered to be poor, average, or good. Data of the several years were not thrown together.

COMPUTATIONS OF DENSITIES AND FORAGE FACTORS

Plot density was obtained by adding the species densities for each plot. The species densities were added to obtain total species density for a series of plots within a vegetation type. Average density of each species in the type was obtained by dividing the total density of each species by the number of plots in the series. Mean density of the type was secured by dividing the sum of the plot densities by the total number of plots.

The forage factor was computed for each plot by multiplying the density of each species by its percentage palatability (2, 3) and adding the products thus obtained. By pointing off two decimal places to the left the forage factor was expressed in terms of forage acres per surface acre. The forage factor is a relative figure and may be used in the comparison of grazing capacities of different areas without reference to grazing capacity in terms of animal months.

RESULTS AND DISCUSSION

RELATION BETWEEN SAMPLING INTENSITY AND STATISTICAL ACCURACY

The number of plots required to give a mean density or a mean forage factor of any desired degree of accuracy was calculated by transposing the formula for the standard error of a mean to the following form (1): $N = \left(\frac{\sigma}{\sigma_M}\right)^2$, in which the standard deviation (σ)

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[5]In the square-foot density method, density is estimated on circular plots, 100 square feet in area. The unit of estimation is a square-foot of area completely covered by vegetation when viewed from directly above. When vegetation does not completely cover the ground, individual plants are mentally amassed into square-foot units of total (10/10) density. The number of square foot units are counted for each species on a plot and recorded in square feet or fractions thereof on the examiner's field data sheet (Form 764b). The examiner's density concept is frequently checked by picking the vegetation and placing it at 10/10 density in a wire frame 1 foot square.

was determined from the plot data and the standard error of the mean (σ_M) was given an arbitrary value depending on the accuracy desired. Thus, to provide an index of the number of plots required for accuracies varying from 80 to 99%, standard deviations were computed from samples of 300 to 1,000 plots selected from each of the main vegetation types in Colorado and Wyoming. Allowable errors of 1, 2, 3, 4, 5, 10, and 20% of the mean were substituted for σ_M in the above formula, and N was then computed in each instance. The results of this computation for the sagebrush type in northwestern Colorado are shown graphically in Fig. 1. Values in Fig. 1 are shown at the 5% level of significance (odds of 19:1). This level of significance is used throughout this paper.

The law of diminishing returns applies to sampling of density and grazing capacity. Increase or decrease in sampling error is proportional to the square root of the number of plots. For example, in order to double the accuracy (decrease the error by one-half) the number of plots must be quadrupled. Thus, Fig. 1 indicates that 48 plots examined in the sagebrush type in northwestern Colorado will give a survey accuracy of 90% for density, while 193 plots will only increase the accuracy to 95%. Slight discrepancies from the ratio mentioned

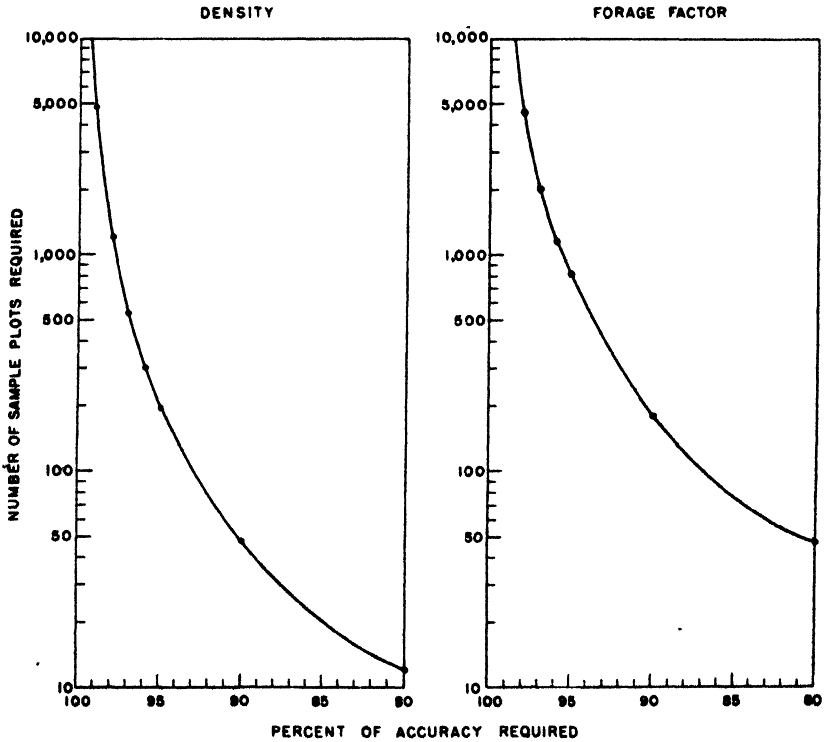

FIG. 1.—Number of plots required for different degrees of sampling accuracy for the sagebrush type in northwestern Colorado.

above occur in actual computation as a result of rounding off numbers. Similar diagrams, constructed from data secured in any vegetation type, will show the same relationships between number of plots and statistical accuracy.

It is obvious from Fig. 1 that accuracies exceeding 95% require an excessive number of plots entailing a cost of field work and analysis which is prohibitive and unwarranted in view of the errors introduced in surveys by factors other than sampling. For example, the examiner's error in using the square-foot density method is seldom less than 5% Seasonal and yearly fluctuations from the average density often exceed 20% and may even be much greater in years of drought or seasons of heavy rainfall. The palatabilities used in computing grazing capacities are approximations and vary from season to season and from one forage type to another. Consequently, sampling intensities which give an accuracy of 80% should be adequate for all practical purposes in range surveys.

RELATION BETWEEN VEGETATION TYPE AND SAMPLING INTENSITY

When the transposed formula for the standard error of a mean is used to compute the number of plots required to give reliable estimates of either density or forage factor, relatively wide variations between vegetation types are found to exist These variations are exemplified in Table 1 by the numbers of plots necessary to sample both density and the forage factor for broad areas of representative forage types in Colorado and Wyoming, within 20, 10, and 5% of the probable true mean (80, 90, and 95% accuracy)

It is evident from these data that the intensity of sampling necessary to secure a given degree of accuracy must vary not only from type to type but within types as they occur in different localities. For instance, the five examples given as representative of the Great Plains short grass type show, in the 80% column, a variation ranging from 12 to 26 plots required for a reliable density estimate and 18 to 44 plots for the forage factor This variability between types and between portions of the same type is largely the result of the different degrees of heterogeneity in vegetation that occur from place to place.

The number of plots necessary to sample the forage factor tends to be larger than the number necessary to sample density. This is the result of greater relative dispersion of forage factors about their means than is the case with the relative dispersions of densities around their means. In Table 1 the greasewood type is the only type requiring fewer plots to sample forage factors than are necessary to sample densities. Densities in a greasewood type are widely dispersed on randomly selected plots owing to the frequent occurrence of barren areas and the occasional occurrence of greasewood or other plants with high densities. Forage factors, however, tend to be less widely dispersed because the majority of plants commonly found in greasewood types are of zero or at most very low palatability. The occasional grasses or other plants of high palatability that may be present usually contribute little to the density. Since the forage factor is the product of density and palatability, the multiplication of low palatabilities by the high densities derived mainly from greasewood and

TABLE 1.—*Number of plots necessary to give reliable estimates of density and forage factor for different degrees of accuracy in representative forage types in Colorado and Wyoming.*

Forage type	Standard type number	Location	Density, number of plots required for accuracy of			Forage factor, number of plots required for accuracy of		
			80%	90%	95%	80%	90%	95%
Mt. bunchgrass	1	National forests in Colorado	18	72	288	26	104	414
Plains short grass	1	Converse County, Wyoming	26	106	423	44	174	697
Plains short grass	1	Northeastern Colorado	12	46	185	19	75	299
Plains short grass	1	Weld Co. (in N. E. Colorado)	14	54	217	18	72	288
Plains short grass	1	Baca Co. (in S. E. Colorado)	21	85	340	30	120	480
Plains short grass	1	Cheyenne Co. (in eastern Colorado)	17	66	256	24	95	381
Saltbush	13	Sweetwater Co. (in S. W. Wyoming)	27	110	438	36	142	569
Sagebrush	4	Moffat Co. (in N. W. Colorado)	12	48	193	46	182	729
Sagebrush	4	National forests in Colorado	15	59	235	75	298	1,192
Sagebrush	4	Sweetwater Co. (S. W. Wyoming)	25	100	399	42	170	678
Annual weed	18	Weld Co. (N. E. Colorado)	33	132	528	56	225	902
Oakbrush	5	National forests (S. W. Colorado)	22	90	360	47	186	744
Greasewood	14	Moffat Co. (in N. W. Colorado)	35	139	557	34	134	538
Greasewood	14	Sweetwater Co. (S. W. Wyoming)	65	260	1,039	52	207	826
Conifer	6	National forests in Colorado	20	80	322	68	273	1,091
Dry Mt. meadow	2D	National forests in Colorado	19	76	303	51	203	812
Wet Mt. meadow	2W	National forests in Colorado	22	87	347	38	152	606

other shrubby species, and the multiplication of low densities by high palatabilities derived principally from grasses, causes forage factors to be grouped about their mean closer than is the case with density values.

The data presented in Table 1 indicate also that an approximate maximum limit can be established for the probable number of plots necessary to sample any broad range type within a given degree of accuracy. Thus, 33 plots will sample the density and 56 plots will sample the forage factor with 80% or greater accuracy in all but two of the types listed. These figures, of course, apply to the types as a whole. Specific portions of any type may show either more or less heterogeneity than the average area within the type. If uniform accuracy is desired in a survey involving different vegetation types, different sampling intensities usually will be required for each type.

RELATION BETWEEN AREA AND SAMPLING INTENSITY

The number of plots needed for a reliable estimate of either density or forage factor is not proportional to the area of the type to be sampled. Apparently, the number of plots needed is mostly dependent upon heterogeneity of the vegetation cover and is related to area only as heterogeneity is related to area.

The dispersion of plot values found within a portion of a type may be as great as the dispersion within the entire type. Any two plots located at random in a forage type may represent the upper and lower limits of density or forage factor that will be encountered. The first of the two plots may fall on barren soil and the second in dense vegetation, irrespective of the size of area in which they are chosen.

Table 2 presents the accuracy obtained when samples of 100 plots each were selected at random for areas of increasing size in the short

TABLE 2. —*Accuracy obtained by samples of 100 plots on areas of different size.*

Size of area, sq. miles	Percentage of accuracy obtained	
	Density	Forage factor
1	93.23	90.87
2	92.66	91.24
4	94.01	92.02
8	90.82	88.39
12	89.26	88.42
16	91.72	88.24
20	90.60	86.90
100	89.65	86.78
10,000	91.85	85.79

grass type in northeastern Colorado. The percentages of accuracy obtained for density and for the forage factor were computed for samples of 100 plots selected for each area. The accuracy of density estimates falls in the narrow range of 89.26 to 94.01%. Accuracy of the forage factor estimates shows a slightly greater range, 85.79 to 92.02%. The percentages of accuracy obtained are significantly uniform in both cases. The accuracy of the forage factor appears to

diminish with increasing size of area. Data from intensive surveys are not available to test whether or not the trend observed would appear in similar samples taken in other localities and in other types.

CONDITIONS AFFECTING SAMPLING INTENSITY WITHIN VEGETATION TYPES

Type heterogeneity.—In surveys designed to secure data for range management purposes, plot transects, usually consisting of 3 to 20 plots, are located in each vegetation type or subtype within a section, or a management unit. Grazing capacities are then computed for each series of plots. Thus, the basis for determining the intensity of sampling to be used in a detailed survey lies in the data obtained from each localized area of a vegetation type rather than in data consisting of a composite sample of plots taken in many portions of the entire type. Any specific portion of a type may require a different number of plots for a given accuracy than any other portion of the type. Hence, in order to survey a range area with statistical uniformity, the required number of plots would have to be determined for each portion of a type on which a plot transect was taken. This is impractical when large areas are being surveyed intensively.

The practical solution to this problem is to determine the number of plots that would be required to sample various portions of each vegetation type on which a plot transect would be taken. The numbers of plots required for different transects can be arranged in a cumulative frequency distribution to show both the number and percentage of areas within a type which require "*more than*" or "*less than*" a given number of plots for a reliable sample.

In a study of type heterogeneity in the mountain bunchgrass type on the east slope of Colorado, the results shown in Table 3 were secured. The numbers of plots required for 80% accuracy on each of 25 areas within the type were assembled cumulatively and the frequencies were reduced to percentages. The table indicates that 35

TABLE 3.—*Cumulative distribution of 25 transects in the mountain bunchgrass type, classified according to the number of plots required for 80% accuracy*

Number of plots required	Number of areas (frequency)	Cumulative frequency	
		Number of areas	%
35	2	2	8
45	5	7	28
55	8	15	60
65	6	21	84
75	3	24	96
85	1	25	100

plots will sample 8% of the areas with 80% accuracy, 45 plots will sample 28% of the areas, and so on. Information of this kind may be used as a basis for establishing the average number of plots for each transect that would be commensurate with the purpose of the survey.

Range conditions.—Range conditions on different portions of a type may be classed as poor, average, or good. If these conditions

within a type are sampled independently the number of plots required for each differs from the number required when the plots from all conditions are combined into a single sample.

In Table 4 the results of breaking down three types into three classes based on grazing capacity are shown. The number of plots required to sample the various range condition classes within a given degree of accuracy is less in each instance than the number required for the composite sample The total number of plots required to sample the type by condition classes, however, is greater than the number required for the type as a single unit. If the number of classes of range conditions were increased beyond three the total number of required plots also would be increased Under field conditions any attempt to fit sampling intensities to classes of range condition probably would be unwarranted and of doubtful accuracy

TABLE 4 *Number of plots necessary for 80% forage factor accuracy for different range conditions within each of three forage types*

Type	Condition of the range			Total	Composite sample
	Poor	Average	Good		
Dry mountain meadow	34	19	22	75	51
Mountain bunchgrass	12	6	16	34	26
Plains short grass	62	51	40	153	67

Seasonal changes Table 5 presents the results of computing the number of plots required to sample a 320-acre short grass subtype with the same degree of accuracy from May to October, inclusive A series of 50 permanently marked plots were surveyed at the beginning of each month, with the exception of September Fluctuations in the mean forage factor from month to month are expressions of both climate and forage compositions The marked rise in forage value for June is due mainly to rapid growth of blue grama and to the

TABLE 5 —*Seasonal change in sampling intensity on a plains short grass subtype in eastern Colorado in 1938.*

Month	Mean forage factor	Standard deviation	Number of plots (80% accuracy)
May	5.180	±2.269	20
June	10.592	±5 151	25
July, ...	6.969	±2 796	17
August	4.634	±1.448	11
October	6 741	±2 844	19

appearance of weeds of low palatability. In July and August, growth practically ceased and a considerable portion of the vegetation, which became dry and brown, disintegrated and was lost as forage. September rains, resulting in regrowth, probably account for the increase in forage available in October. Clipping studies and dry forage weight determinations made independently of this study show similar

trends and hence indicate that the fluctuations shown in Table 5 are real and not the result of a change in density base on the part of the observers.

Yearly changes.—Table 6 shows the variation in sampling intensity over a period of 3 years for a short grass subtype similar to the one discussed above. These computations are based on a series of 40 permanent plots which were surveyed in September of each year. Forage value was low in 1936, reflecting the effects of drought extending from 1934. Extremely favorable rainfall in 1938 resulted in an excellent forage crop in that year. Much of the variability between years in this example is the result of density changes and changes in relative floristic composition with their accompanying palatability changes. Data similar to those shown in Table 6 are not available for other forage types, but general observation indicates that analogous changes may be expected in other types and other localities.

TABLE 6.—*Yearly change in sampling intensity on a plains short grass subtype in eastern Colorado.*

Year	Mean forage factor	Standard deviation	Number of plots (80% accuracy)
1936	3.012	±0.559	4
1937	3.216	±1.137	14
1938	8.086	±3.549	20

APPLICATIONS

In view of the results presented in preceding paragraphs it is apparent that an arbitrary number of plots cannot be proposed as a means of securing adequate sampling of all types with uniform accuracy on all range units covered by a survey. The purpose of the survey and the nature of the vegetation dictate the basis for establishing the number of plots necessary to sample various types. For example, the use of samples derived from broad types is justified when averages of grazing capacity are needed by such agencies as the Agricultural Adjustment Administration for state and regional planning; a different type of sample is needed when grazing capacities of ranches are required; and lastly, in detailed surveys from which management plans are to be prepared, the adequacy of the sample on individual transects must be considered.

A preliminary sample from which the number of plots needed for a survey of a given accuracy may be calculated by means of standard statistical formulae appears to be more logical than any attempt to establish the required number of plots on a purely arbitrary basis. If a preliminary survey is not feasible, data collected during the course of the survey itself may be analyzed to determine the adequacy of the number of plots being secured. In view of seasonal fluctuations that may be encountered in the survey, samples for preliminary analysis may be taken periodically to provide a basis for adjustment in intensity with season. New samples should also be analyzed as new types are encountered.

In all procedures used for establishing plot numbers, good judgment will be required. For example, a 3,000-acre ranch may have the following statistics:

Forage type	Acres	Forage factor	Forage acres	Percentage of grazing capacity
Grassland	2,100	0.03515	73.815	76.55
Annuals . .	300	0.00250	0.750	0.78
Sagebrush	450	0.00640	2 880	2.99
Meadow	150	0.12650	18 975	19.68
	3,000		96 420	100 00

In this example, grassland and meadow types should be sampled more adequately than the sagebrush type A 50% error in sampling the sagebrush type would result in less than 1 5% error in the total grazing capacity of the ranch. A statistically adequate sample of the annual type would be a waste of time and money

When portions of a large type or management unit are surveyed by sections or other legal subdivisions, more plots than necessary may result from repetition of plot transects. In such cases, fewer plots may be established without impairing sampling accuracy and the time thus saved may be allotted to important grazing types of small area or of infrequent occurrence, in order to obtain more accurate estimates Careful judgment in certain instances should even make possible the allocation of plots saved from large management units to small management units in key locations The use of aerial photographs from which types and their acreages can be determined before plots are taken should facilitate this process.

SUMMARY AND CONCLUSIONS

A study of sampling intensity as it applies to the use of the square-foot density method in range surveys was made with sample plot data recorded from range surveys on all of the major range vegetation types in Colorado, Wyoming, and the Black Hills region of South Dakota

The law of diminishing returns applies to accuracy of surveys by the plot method Sampling error is proportional to the square root of the number of plots taken.

Different vegetation types require different numbers of plots to secure a given degree of sampling accuracy.

Little relationship exists between the area of a vegetation type and the number of plots necessary to sample it with a given degree of accuracy.

Different portions of a type generally require different numbers of plots for a given degree of accuracy.

Subdividing types on the basis of range conditions and sampling these conditions independently requires fewer plots for each condition class than are required to sample a broad area of the type to the same degree of accuracy. The total number of plots required for all con-

dition classes, however, is greater than the number required for a composite sample of the same area.

Seasonal and yearly fluctuations in floristic composition result in seasonal and yearly fluctuations in the sampling intensity necessary to survey the same area with a given degree of accuracy.

Either a preliminary survey or samples taken periodically from the survey data appear to provide a satisfactory basis for determining the intensity of sampling required in different types.

Plots can be saved by less intensive sampling of large grazing units or vegetation types and by less intensive sampling of types of low grazing capacity. Plots saved can be allotted to small grazing units and small areas of important vegetation types.

LITERATURE CITED

1. BRUCE, DONALD, and SCHUMACHER, FRANCES X. Forest Mensuration. New York: McGraw Hill Book Co. 1935. (Page 79.)
2. COSTELLO, DAVID F. Check list, palatability table and standard symbol list of Colorado and Wyoming range plants. Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo. Progress Report No. 5. 41 pages. 1937. (Mimeographed.)
3. INTERAGENCY RANGE SURVEY COMMITTEE. Instructions for Range Surveys. 30 pages. April 1937. (Mimeographed.)
4. STEWART, GEORGE, and HUTCHINGS, S. S. The point-observation-plot (square foot density) method of vegetation survey. Jour. Amer. Soc. Agron., 28:714-722. 1936.

HEAT RESISTANCE IN OAT VARIETIES[1]

FRANKLIN A. COFFMAN[2]

OATS are generally considered to be less tolerant to heat than any of the leading cereal crops. Despite this situation, the major oat-producing areas of the United States frequently experience high temperatures during the most critical periods of the growth of the crop, and decreased yields of oats resulting from heat and attendant drought are very common. Consequently, any information helpful in preventing or reducing such losses is of interest to oat breeders, farmers, and others.

Statements, presumably based upon observation or deduction, frequently have been published to the effect that red oats, i.e., varieties belonging to *Avena byzantina*, supposedly derivative from the wild *A. sterilis*, are more heat resistant than are the common oat varieties of *A. sativa*, which supposedly are derived from *A. fatua*. Red oats are more widely grown in southern United States and in California, and the warmer sections of the world where oats are produced. Published data on the comparative heat resistance of oat varieties have not been presented, however. Laboratory tests of the heat resistance of oat plants were begun in 1936 in order to obtain some information on this subject. The experiments were limited to young plants, and the results reported here on the relative heat resistance of individual varieties should be considered merely as preliminary indications.

MATERIALS AND METHODS

Much time was consumed in devising a technic which would indicate differences between varieties in heat resistance. The equipment available was a Freas electrically-operated, thermostatically-controlled oven used primarily for the drying of plant materials. The heat in this oven is produced by a current of air passing over electrically-heated coils. The warm air is forced through the oven by a motor-driven fan. The oven temperature was maintained within a range of 2½° to 3° C.

Originally the minimum temperature possible in the oven was about 60° C. Tests indicated this temperature was too severe for oat plants even when the period of exposure was as short as 45 minutes. After some adjustments, however, it was possible to obtain a temperature control ranging from some 48½° to 52° C, which was used in most of the tests.

Two asbestos baffle plates were inserted in the oven, one on the windward side and one at the top to deflect the direct hot-air blast from the plants.[3] The current of hot air was still sufficient to keep the leaves of the oat plants almost constantly in motion.

The pots containing the oat plants were set in a pan containing about 2 inches of water in order to retard drying. This tended to reduce the heat from the bottom

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication July 13, 1939.

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[3]The writer is indebted to C. H. Kyle, senior agronomist, Division of Cereal Crops and Diseases, for assistance in the technic used for testing plants to heat.

of the oven and was helpful in cooling the pots and soil. The water was replenished as it evaporated.

In all the tests on which data are presented, only two pots were placed in the oven at a time. The area of the oven, after the asbestos plates had been inserted, was approximately 16 inches wide, 12 inches high, and 17 inches deep. After one-half the exposure period had elapsed, the position of the pots in the oven was reversed and each pot was then turned so that all of the plants might have, as nearly as possible, the same exposure to the heated air.

Various arrangements of planting the seed in the pots were tried during the course of the experiments. In 1936–37, about six plants were grown per pot. In the test conducted in 1937–38, 6-inch pots were used and two kernels of each of 10 varieties were sown per pot. In all tests in 1938–39, 5-inch pots were used for growing the plants. In one test, two seeds of each of six varieties were sown in a pot, and in another test, four kernels of each of two varieties were alternated. In the most recent tests, five kernels of each of two varieties were planted alternately in a pot.

Preliminary experiments indicated that Fulghum (C. I. 708)[4] was much superior to any of the other varieties tested for heat resistance, and this variety was used as a check in all later tests. Where two varieties were sown alternately in a pot, Fulghum was one of the varieties, and the survival of each variety was calculated in percentage of the check.

DATA OBTAINED

In 1936–37, oat plants in 10 pots were tested for heat resistance at a temperature of some 59° to 60° C. with exposures of 3 to 4 hours. These tests were so severe that only one plant of the Fulghum (C.I. 708) variety survived.

A second series of tests was made in 1937–38 at a temperature range of 48½° to 50° C. Exposure periods ranged from 45 minutes to 4 hours as follows: Two pots for 4 hours, six for 3 hours, four for 2 hours, four for 1 hour, and four for 45 minutes. Two seeds each of 10 varieties were planted in each of 20 6-inch pots so that all varieties presumably had equal exposures. The results indicated that the exposures were still much too severe for oats, but gave further evidence that Fulghum (C.I. 708) was more heat resistant than any of the other varieties then tested. Among the 10 varieties tested, 5 are classed as belonging to *Avena byzantina*, 4 to *A. sativa*, and 1 to *A. sativa orientalis*. The varieties of the latter two groups were alternated with those of *A. byzantina* varieties in seeding. Most of the plants in all pots succumbed but a few survived, usually in pots exposed for the shortest period. The percentage of survival of the different varieties was as follows: Fulghum (C.I. 708), 30.8; Ferguson 71 (Red Rustproof) (C.I. 1039), 10.0; Storm King (C.I. 1602), 8.1; and Coastblack (C.I. 1025), 8.0. The remaining varieties, Markton (C.I. 2053), Brunker (C.I. 2054), Richland (C.I. 787), Victory (C.I. 1145), Cornellian (C.I. 1842), and Red Algerian (C.I. 840), did not survive. In these tests, it seemed that the varieties of *A. sativa* were less heat resistant than those of *A. byzantina*, but this

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

generalization was not confirmed in later tests when additional varieties were tested

Three experiments were conducted in 1938–39. In the first experiment, two seeds of each of six varieties were sown in each of 35 pots. Thus 69 or 70 plants of each variety were tested. The plants were exposed as follows: 12 pots for 2 hours, 9 pots for 1½ hours, and 12 pots for 1 hour, at a temperature range of 48½° to 52° C. The survival of Fulghum (C.I. 708) was 7.1% after a 2-hour exposure, 11.1% after 1½ hours, and 43.5% after 1 hour. The average survival was 20.3%. No plants of Richland (C.I. 787) survived in any test. In relative survival, calculated on the basis of the survival of the Fulghum check considered as 100%, Victory survived 6.9%, Markton 21.2%, Brunker 28.6%, and Ferguson 71.35%. Fulghum, alone, survived when the exposure was longer than 1 hour. The superiority of Fulghum was notable.

In the second experiment, the same six varieties were sown in 50 pots. Four seeds of Fulghum were sown in each pot alternating with four seeds of one of the other five varieties. Thus, each of the five other varieties was compared with Fulghum in 10 pots. Periods of exposure to heat were one pot for 2 hours, one for 1½ hours, six for 1 hour, and two for 45 minutes at a temperature range of 48½° to 52° C. The data obtained are presented in Table 1. For some reason the Fulghum plants in the pots exposed for 2 hours, all of which were exposed on the same day, survived much better than when exposed for shorter periods. One plant of Ferguson 71 also survived at that exposure. The reason for this is not known Possibly the oven was not

TABLE 1.—*Survival of five oat varieties compared with Fulghum (C. I 708), after different periods of exposure to a temperature of 48½° to 52° C.*

Variety	C. I. No.	Percentage survival after exposure for				Average all tests (40 plants)	Percentage of check
		2 hours (4 plants)	1½ hours (4 plants)	1 hour (24 plants)	45 minutes (8 plants)		
Victory	1145	0	0	4.2	121.5	5.0	16.4
Fulghum	708	0	50.0	12.5	100.0	30.5	—
Markton	2053	0	0	4.2	50.0	12.5	25.0
Fulghum	708	75.0	0	37.5	100.0	50.0	—
Brunker	2054	0	0	4.2	28.6*	7.7	14.0
Fulghum	708	0	0	41.7	100.0	55.0	—
Richland	787	0	0	0	0	0	0
Fulghum	708	100.0	0	29.2	88.8	45.0	—
Ferguson 71 (Red Rustproof)	1039	33.3*	0*	17.4*	37.5	21.6	72.0
Fulghum	708	25.0	0	29.2	50.0	30.0	—
Average for Fulghum		40.0	10.5	30.0	87.5	42.7	100.0

*One less plant.

functioning normally and the fact was not detected, or else some environmental condition influenced the heat resistance of Fulghum and Ferguson 71 oats that day. With the exception of data for that one day, these tests usually have resulted in progressive increases in survival as the period of exposure to heat was shortened. No plants of any of the other varieties survived when exposed for longer than one hour.

An average of 42.7% of the plants of Fulghum survived in this experiment (Table 1). Considering the survival of Fulghum as 100, the other varieties survived as follows: Ferguson 71 (Red Rustproof), 72%; Markton, 25%; Victory, 16.4%; Brunker, 14%; and Richland, none. It is difficult to explain why Richland failed to survive in these tests. In later tests in which the period of exposure to heat was reduced, Richland showed some tolerance to heat.

In the third experiment in 1938-39, 10 pots each of 23 varieties were sown along with the Fulghum check in each pot Eight pots of one additional variety were grown in a similar manner. Five seeds of a variety were sown in a pot in alternation with five seeds of Fulghum. The seedlings were made at 1-week intervals, two pots of each variety pair on each date. All pots were exposed in the oven for 45 minutes at the heat range of 48½° to 52° C. Except in the final series of plantings, all the plants were in the five-leaf stage of development when exposed to heat. Due to an oversight the plants in the fifth or final replicate were exposed to the stimulating influence of an artificial light throughout the nights. Although located some distance away, the light caused some variation in the stage of development of these plants. The data obtained, however, do not indicate that the heat resistance of the plants was greatly influenced by the light.

A wide range of varieties was included in this test. About half of the varieties are classed morphologically as belonging to *Avena byzantina* and half to *A. sativa*. The White Russian (White Tartar) variety of *A. sativa orientalis* was included. Midseason, early-maturing, and one late-maturing variety were tested along with the leading varieties of winter oats. Fulghum and Appler (Red Rustproof) oats, shown to be resistant to heat, usually are grown from fall, winter, or early spring seeding and are known to require some cool temperatures in early stages for normal growth and development. They also have considerable cold resistance. It seemed desirable, therefore, to include other varieties of winter oats in the heat experiments.[5] The comparative cold resistance of certain of the winter oat varieties is shown in Table 2. Varieties highly resistant to stem rust, crown rust, and smut were tested. Oat varieties having no dormancy and those having differing degrees of dormancy in freshly harvested seed were included. Black, gray, red, yellow, and white oats; awnless and awned varieties; varieties with and without basal scars; and varieties with and without pubescence were tested.

[5]The writer is indebted to S. C. Salmon, principal agronomist, Division of Cereal Crops and Diseases, for suggesting that heat resistance of winter oats as well as spring oats be investigated.

TABLE 2.—*Comparative survival of 25 varieties of oats after 45 minutes in an oven at 48½° to 52° C.*

Variety	C.I. No.	Plants survived		Percentage of Fulghum, C.I. 708, check as 100	
		Variety named, %	Comparable Fulghum, %	Heat test, %	Hardiness test*, %
		Early Maturing, Spring			
Brunker	2054	6.1	30.0	20.3	—
Black Mesdag	1877	20.4	57.1	35.7	—
Columbia	2820	18.0	32.0	56.2	—
Early Joanette†	1092	5.1	12.5	40.8	—
Richland	787	16.0	29.2	54.8	—
Victoria × Richland	3500	6.4	25.0	25.6	—
Average		12.0	31.0	38.9	
		Midseason, Spring			
Bond	2733	20.4	43.8	46.6	63.8
Joanette	1880	26.0	50.0	52.0	—
Markton	2053	14.3	46.9	30.5	—
Rainbow	2345	12.5	31.3	39.9	—
Victoria	2401	22.4	52.1	43.0	46.8
Victory	1145	14.0	38.0	36.8	—
Average		18.3	42.7	41.5	55.3
		Late, Spring			
White Russian (White Tartar)	1614	4.1	24.5	16.7	—
Average		4.1	24.5	16.7	
		Intermediate, Spring-Winter			
Appler	1815	56.0	70.0	80.5	105.8
Fulghum	708‡	40.8	40.8	100.0	100.0
Navarro	966	53.1	52.1	101.9	—
Ruakura	2025	59.2	40.0	148.0	—
Average		51.8	50.6	107.5	102.9
		Winter			
Bicknell	3218	44.9	36.0	124.7	117.6
Culred	3217	36.0	30.0	120.0	108.6
Fulghum	2499	66.0	66.7	99.0	113.7
Fulwin	3168	66.0	52.1	126.7	106.3
Hairy Culberson	2505	68.0	55.1	123.4	118.7
Lee	2042	34.7	34.7	100.0	111.0
Tech	947	61.2	58.0	105.5	109.2
Winter Turf	3296	67.3	60.0	112.2	111.0
Average		56.0	49.1	113.9	112.0

*Data from extensive cooperative uniform hardiness nursery tests conducted at several experiment stations.
†Only eight pots were tested, whereas 10 were tested of all other varieties.
‡Average of all pots.

From the results shown in Table 2, it would seem that the only characters specifically associated with heat resistance were those of partial to complete winter growth habit and cold resistance. It was surprising that varieties belonging to *Avena byzantina* were not, on the whole, more heat resistant than are those of *A. sativa*. Only those having some cold resistance or being more or less of the winter type, and adapted to the South, were notably heat resistant.

DISCUSSION

The data obtained indicate that varieties which are more or less winter resistant are apt to be heat resistant as well. It was rather surprising that red oats were not more heat resistant than many varieties of so-called common oats. Possibly, if the plants had been subjected to some sort of hardening, different results would have been obtained. It also is not known how nearly the laboratory set-up approached natural or field conditions. Evidently, from the results obtained heat resistance is not related to any of the characters making for resistance to the major diseases of oats.

The factors responsible for heat resistance in oats would appear to be similar to those that are generally considered to enable plants to resist cold. Either extreme heat or heavy freezing causes a withdrawal of water from plant cells. The close association between heat resistance and cold resistance in oats would suggest that hydrophyllic colloids which retain water in the protoplasm with a considerable inhibitional force are abundant in the resistant varieties

The fact that heat resistance seems closely related to winter resistance is of interest to plant breeders. If future tests show that heat resistance is a reliable index of winter resistance, the testing of hybrid populations for cold resistance will be greatly simplified. Heat tests can be made in ovens which are more commonly available and less expensive than refrigeration equipment.

The possibilities of breeding for heat resistance in oats would seem to be favorable. Although most of the typical spring oats seem to lack heat resistance, the varieties appear to vary somewhat. Fulghum oats sown in early spring mature normally, and this variety has a marked ability to resist heat. Ruakura, which also matures normally when spring sown, would seem by these tests to have unusual heat resistance. It would seem possible to obtain spring-like oats with more heat resistance than are our present leading spring oat varieties. It is not difficult to conceive of seasons in which heat resistance would be as important a character to an oat variety as is rust resistance in a season when rust is prevalent.

SUMMARY

Oat varieties were subjected to different temperatures for various lengths of time. It was determined that a temperature of 48½° to 52° C for a period of 45 minutes would give results indicating differences in heat resistance of oat varieties. The plants tested were in the five-leaf stage. Experiments were conducted on more than 25 varieties. It was found that varieties differ widely in their ability to

resist heat. Varieties adapted to the South and that are resistant to cold and have at least a partial or intermediate winter growth habit showed the greatest resistance to heat.

Red oats (*Avena byzantina*) as a group were not more heat resistant than many varieties of *A. sativa*. Some varieties belonging to both species were heat resistant. Heat resistance apparently is not correlated with time of maturity, with resistance to any of the major oat diseases, with after-harvest dormancy, or with any of the observed morphological characters of the oat kernel.

GRASSHOPPER INJURY IN RELATION TO STEM RUST IN SPRING WHEAT VARIETIES[1]

RALPH W. SMITH[2]

DIFFERENTIAL injury to cereal crops and varieties by insects is a rather common observation. As a result of insect ravages in recent years, there is an increasing interest in growing field crops resistant to insect injury and also in developing strains less subject to attack by insect pests.

Gilbertson (3)[3] and Dunham (2) report that certain wheat varieties are injured more than others by stem maggot. McColloch and Salmon (6) and Painter, Salmon, and Parker (7) found that certain varieties of winter wheat are more resistant than others to injury by Hessian fly.

Brunson and Painter (1) state that grasshoppers injured corn more than sorghum and that in both crops some varieties were injured more than others. Hume (5) states that dent corn was injured more by grasshoppers than flint corn. Hermann and Eslick (4) observed differential injury caused by grasshoppers in different genera and species and in selections within species in grasses at the Washington Agricultural Experiment Station.

General observation of grasshopper damage to cereal crops in the Dickinson, North Dakota, vicinity in recent years would indicate that these crops, in extent of grasshopper injury, rank in descending order as follows: Barley, oats, wheat, corn, and sorghum During the grasshopper invasion of 1938, which was the worst ever known at the Dickinson substation of the North Dakota Agricultural Experiment Station, estimates were made of the percentage injury from grasshoppers in field plats of spring wheat, oats, and barley. Averages of the four replications of each variety gave the results shown in Table 1.

TABLE 1.—*Average percentages of heads cut off by grasshoppers in field plats of spring wheat, oats, and barley at Dickinson, N Dak, 1938.*

No. of varieties	Crop	Heads wholly or partly cut off, %
24	Spring wheat	38
16	Oats	51
15	Barley	57

In 1938 there also occurred a very destructive epidemic of stem rust in the vicinity of Dickinson. This gave an unusual opportunity to study the correlation between grasshopper injury and percentage of stem rust in spring wheat varieties. The percentage of heads lost through grasshopper injury and the percentage of stem rust were estimated for all varieties in the general spring wheat nursery.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the North Dakota Agricultural Experiment Station. Received for publication July 17, 1939.

[2]Associate Agronomist, Division of Cereal Crops and Diseases.

[3]Reference by number is to "Literature Cited", p. 820.

It was observed that, with a few exceptions, rust-resistant varieties showed limited grasshopper injury, while severely rusted varieties, in general, were badly injured by the insects. Correlation coefficients calculated for different sections of the nursery are shown in Table 2. These rather high correlations show a decided tendency for grasshopper injury to increase with an increase in rust prevalence. The varieties in groups 1 and 2 were consecutive, while in group 3 all varieties having only a trace of rust were omitted.

TABLE 2.—*Correlations between percentage of heads cut off by grasshoppers and percentage of stem rust in varieties of spring wheat at Dickinson, N. Dak., 1938.*

Group	No. of varieties	Heads cut off, %			Stem rust, %			Correlation between grasshopper injury and stem rust
		Max.	Min.	Av.	Max.	Min.	Av.	
1	100	95	10	51.7	75	0	39.4	$r = +0.767 \pm 0.028$
2	225	100	10	42.9	75	0	17.1	$r = +0.512 \pm 0.033$
3	256	100	10	51.5	75	0	36.7	$r = +0.787 \pm 0.016$

The varieties or strains of wheat studied were mostly unnamed hybrid selections. A few named varieties were included and the data recorded in Table 3 show, in general, a decrease in grasshopper injury as the percentage of rust decreases. A marked exception is Hard Federation in which the strong peduncle evidently enables it to resist hopper injury despite its high susceptibility to rust.

TABLE 3.—*Estimated percentage of heads cut off by grasshoppers and percentage of stem rust in 14 varieties of spring wheat at Dickinson, N. Dak., 1938.*

Variety	Heads cut off, %	Stem rust, %
Reward	95	75
Reliance	93	75
Red Fife	90	75
Haynes	85	70
Marquis	80	75
Ceres	72	73
Supreme	60	75
Kota	60	60
Komar	58	73
H-44	35	15
Thatcher	31	6
Hope	20	2
Pilot	20	2
Hard Federation	15	75

Several theories have been advanced to explain why badly rusted varieties are injured more by grasshoppers than rust-resistant varieties, but the writer is unable to state which of the following factors are important: (a) It has been suggested that a changed chemical content of the rusted stems, such as a greater sugar percentage, makes them preferred by the insects; (b) another theory is that the high protein content of the rust spores (18% in one sample) makes them

attractive to the hoppers; (c) some varieties have stems that are softer or more juicy, and hence are more attractive to the insects; (d) perhaps the fact that wheat stems punctured by rust pustules are more easily broken over and chewed off than are normal stems accounts for much of the difference.

The writer has no evidence to indicate that rust-resistant varieties are less palatable to grasshoppers than susceptible varieties when rust is not present; also, evidence is lacking with which to determine to what extent the insects prefer rusted to rust-free grain, or whether the difference lies mainly in greater ease of destruction of the former.

The stage of maturity of the plants seems to have considerable influence on the amount of injury but cannot account for all of the differences noted as both early and late varieties are found in both the badly injured and slightly injured groups

The greater number of the grasshoppers present in 1938 were identified by entomologists as the lesser migratory species, *Melanoplus mexicanus* (Sauss). Locally hatched hoppers that survived poisoning were augmented by swarms that blew in with warm south winds, especially on July 10

After the middle of July the number of grasshoppers was gradually reduced, apparently due to migration with the wind to the north or northwest. Enough remained, however, to lay sufficient eggs to menace the crop of 1939

SUMMARY

The leading cereal crops at Dickinson, N. Dak , in the extent of grasshopper injury, ranked in descending order as follows. Barley, oats, wheat, corn, and sorghum.

Certain spring wheat varieties were injured by the grasshoppers more than others.

With some exceptions, badly rusted wheat varieties were injured considerably more than those showing but little rust In three different groups of spring wheat in the nursery the correlation coefficients between percentage of stem rust and percentage of grasshopper injury were $r = +0.512 \pm .033, +0.767 \pm .028$, and $+0.787 \pm .016$.

Several unconfirmed reasons are suggested for the greater damage to rusted varieties.

The stage of maturity of a variety seems important but apparently cannot account for all the differences since both early and late varieties were found in both the badly injured and slightly injured groups.

LITERATURE CITED

1. BRUNSON, A. M., and PAINTER, R. H. Differential feeding of grasshoppers on corn and sorghums. Jour. Amer. Soc. Agron., 30:334–346. 1938.
2. DUNHAM, R. S. Stem maggot injury among wheat varieties Jour. Amer. Soc. Agron., 26:978–980. 1934.
3. GILBERTSON, G. I. The wheat stem maggot. S. Dak. Agr. Exp. Sta. Bul. 217. 1925.
4. HERMANN, WILFORD, and ESLICK, ROBERT. Susceptibility of seedling grasses to damage by grasshoppers. Jour. Amer. Soc. Agron., 31:333–337. 1939.

5. HUME, A N. An indication of the relative susceptibility of dent and flint corn to injury by grasshoppers. Jour. Amer. Soc. Agron., 23:1071. 1931.
6. MCCOLLOCH, JAMES W., and SALMON, S. C. Relation of kinds and varieties of grain to Hessian-fly injury. Jour. Agr. Res., 12:519–527. 1918.
7. PAINTER, R. H., SALMON, S. C., and PARKER, J. H. Resistance of varieties of winter wheat to Hessian fly. Kans. Agr. Exp. Sta. Tech. Bul. 27. 1931.

NOTE

HARVESTING BUFFALO GRASS SEED FOR INDIVIDUAL USE

BUFFALO grass seed was successfully harvested at the Blackland Experiment Station at Temple, Texas, this season during the last week in June, at the rate of about 1 pound per man hour cleaned unhulle weight. A lawn mower was prepared for the job by removing the cutter bar, taking off the roller, attaching an ordinary grass catcher, and placing a shield on top of the mower and up the handle to deflect the scattering seed into the catcher (Fig. 1).

FIG. 1.—An ordinary lawn mower reconstructed to harvest buffalo grass seed.

This machine was used on a buffalo grass lawn that had been mowed regularly and on a field area that had been cut with a mowing machine immediately prior to the seed collecting operation. In both cases satisfactory amounts of seed were secured. On the lawn, earthworms had worked up considerable soil which was caught with the buffalo grass seed. This soil was removed by placing the catch in a tub of water and skimming the seed from the top.

By using this method of collecting seed, the amount of hay that is caught in addition to the seed is materially reduced by removing the cutter bar on the lawn mower. The separating process is thus simplified so that the coarser surplus hay is easily removed by hand. Fanning is then effective in the removal of the smaller trash particles. Neither the floating nor the fanning need be done if the seed are to be planted by the collector.

This economical method of harvesting buffalo grass seed will make possible the seeding of pastures to this grass, an operation that has not been practicable because of the difficulty in securing a seed supply.—H. O. HILL, *Texas Blackland Experiment Station, Temple, Texas.*

AGRONOMIC AFFAIRS

NO CHANGE IN DATE OF ANNUAL MEETINGS

REGARDLESS of the dates established nationally or locally for the celebration of Thanksgiving Day, the announced dates for the annual meetings of the American Society of Agronomy and of the Soil Science Society of America will remain unchanged. The two societies will meet at the Hotel Roosevelt in New Orleans November 22, 23, and 24, according to official confirmation by the executive committee.

VOLUME I OF PROCEEDINGS REPRINTED

VOLUME I of the PROCEEDINGS of the Soil Science Society of America has been reprinted and can now be obtained from the Treasurer of the Society, Dr G. G. Pohlman, Agricultural Experiment Station, Morgantown, West Virginia, for $5.00 post paid. The volume contains the papers presented at the 1936 meeting, together with the transactions of the business meeting of the Society for that year, the constitution and by-laws, and other items pertaining to the organization of the Society and the establishment of the PROCEEDINGS.

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"SLICK SPOTS" IN NEBRASKA[1]

J. W. FITTS, H. F. RHOADES, AND E. S. LYONS[2]

IN the Platte and North Platte valleys of Nebraska there are many small areas that will support little or no crop growth. These areas are commonly known as "slick spots" because of their slick, greasy feel when wet. Similar areas have been described by Peterson (10),[3] Isaak (8), Catlin and Vinson (3), Burgess (2), Gardner, Whitney, and Kezer (5), and others..

The slick spots described by these investigators have a puddled structure and are quite impervious to water. It is generally considered that their poor physical condition is due to the presence of sodium ions in the exchange complex of the soil. Peterson (10) found that slick spots in Idaho were considerably higher in carbonate than the normal soils and suggested that the impervious nature of the slick spots was due to the cementing action of calcium carbonate. Isaak (8) noted a higher content of clay in the slick spots.

The slick spots mentioned in this paper are found on the first-bottom lands, particularly in association with Minatare, Laurel, and Lamoure soils, but occasionally they occur on low bench land mapped as Tripp. They vary from a few square feet to several acres in extent and are heterogeneously scattered throughout the fields. Such areas are expensive to the irrigation farmer, especially when the land is in sugar beets. They are so irregular in shape and, in many cases, so small, that they usually cannot be left out of the field. Accordingly, they add to labor costs, often as much as $25.00 an acre of "spots", without contributing any return. Practical experience has amply proved that they cannot be improved by the ordinary practices of culture or fertilization.

Slick spots vary in their adaptability for plant growth If the climatic conditions are favorable when alfalfa is planted, a good stand may be obtained except on the most severe slick spots. However, after

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[2]Assistant Agronomist, Assistant Professor of Agronomy, and Associate Soil Technologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively. The authors wish to express their appreciation for the suggestions and criticisms offered by Prof. J. C. Russel.

[3]Figures in parenthesis refer to "Literature Cited", p. 831.

a few months the alfalfa dies. Under less severe conditions some of the alfalfa may survive. Sorghums and small grains appear to be even more sensitive. Occasionally, sugar beets will grow even in the more severe areas. However, the stand is not uniform and usually the yield is low.

PLAN OF THE INVESTIGATION

Laboratory and field studies are in progress at the Nebraska Agricultural Experiment Station to ascertain the physical and chemical nature of slick spots and to find methods suitable for their reclamation and management. It is the purpose of this paper to report data on mechanical analysis, carbonates, pH, exchange capacity, exchangeable calcium, magnesium, sodium, and potassium, and percentage saturation with sodium and potassium of slick spots and normal soils from four fields. The soil samples used in this study were taken from the following fields.

Field 1.—This field is located in the North Platte Valley, near Minatare, Nebraska. It is mapped as Minatare silt loam (13). The slick spots are numerous and conspicuous. The normal soil is of only medium productivity. The water table occurs at 3 or 4 feet below the surface. This soil is very calcareous. The impervious layers of the slick spot apparently occur at a depth between 10 and 16 inches.

Field 2.—This field is located in the Platte Valley near Lexington, Nebraska. It is mapped as Lamoure very fine sandy loam (6). The slick spots are abundant and conspicuous by their slightly higher elevation and lighter color throughout the profile. The normal soil in the areas sampled is of relatively low productivity, although it is distinctly better than the slick spots. The water level occurs about 6 feet below the surface. This soil is non-calcareous generally above 30 to 36 inches, but in slick spots it is calcareous at a shallower depth. The impervious layer appears to occur between 6 and 9 inches, but the soil below is distinctly impervious also.

Field 3.—This field is located in the North Platte Valley near Scottsbluff, Nebraska. It is mapped as Tripp fine sandy loam (13). Slick spots, varying in severity, are scattered throughout the field. The water level occurs about 6 feet below the surface. The soil is only slightly calcareous in the surface but has relatively large amounts of lime in the lower depth. Slick spots have more lime in layers close to the surface than the normal areas. The slick spot sampled in this field was unique in the abruptness in which the impervious layer occurred. The upper 8 inches had a fair structure, but immediately below there was a very impervious sticky plastic layer.

Field 4.—This field is located in the North Platte Valley near Bridgeport. It is mapped as Laurel very fine sandy loam (7). The slick spots are conspicuous because of their slightly higher elevation and lighter color. The water level occurs about 5 feet below the surface. This soil is calcareous in both normal and slick spot areas. The impervious layer occurs at 7 inches and is distinctly impervious to a depth of 29 inches. The normal soil is of average productivity.

SOIL SAMPLING

The slick spots in Nebraska vary a great deal in their profile characteristics and their adaptability for crop growth. They vary greatly within the same field and even in a given slick spot. The impervious layers do not always occur at the same depth. If the impervious layer occurs at or near the surface an unfavorable

condition results. The depth below the surface and the thickness of the impervious layer determine largely the ability of the slick spot to absorb water and to support crop growth. However, normal soils[4] in those fields containing slick spots are only medium in productivity and may be considered as the "best conditions" found in the field.

Because of the heterogeneity of these spots, it was deemed unwise to take a large number of samples from different spots at given depths and composite them. Instead, trenches were dug in selected slick spots and representative samples were taken for each layer from the face of the pit. A trench was then dug in a normal area as close to the slick spot as possible, and samples were taken from corresponding depths. It was found in almost every case that the depth of the layers in the normal soils was about the same as in the corresponding slick spot.

EXPERIMENTAL

MECHANICAL ANALYSIS

Mechanical analysis was made according to the Robinson pipette method as modified by Engle and Yoder (4). The centrifuge used was of the usual type built by the International Equipment Company for the mechanical analysis of soils. The speed of the centrifuge was 1,200 r.p.m. and the minimum time of centrifuging was 2 minutes. Engle and Yoder did not recommend this procedure for alkali or highly calcareous soils. However, the small amount of soluble salts (0.2% or less) or the large quantity of calcium carbonate present in the soils studied did not seem to interfere with the analysis. The data indicate that practically all of the calcium carbonate was found in the separate less than 0.005 mm

The above method was slightly modified to determine the carbonate-free particles less than 0.005 mm. A quantity of air-dry soil equivalent to 15 grams of oven-dry soil was placed in a small beaker, moistened with distilled water, and 3 N hydrochloric acid was added a few drops at a time until effervescence ceased. A few more drops of acid and about 100 cc of water were then added and the mixture thoroughly stirred. The quantity of calcium chloride formed by the addition of hydrochloric acid to the highly calcareous soils caused the finer separate to flocculate upon standing. To overcome this, two portions of the separate less than 0.005 mm were determined for each sample. The first determination was made by allowing the soil and water mixture to stand overnight. The clear supernatant liquid was then decanted and the soil washed into a centrifuge tube. After centrifuging 10 or 12 minutes, the clear supernatent liquid was decanted and discarded. This procedure was repeated until a trace of suspension appeared in the supernatent liquid. After that, the supernatent liquid was decanted into a large cylinder and the soil remaining in the tube was deflocculated by adding a few drops of ammonium hydroxide and triturating. With repeated centrifuging the time was reduced to 2 minutes. The supernatent liquid was relatively clear after about 900 cc of suspension had been collected. Distilled water was then added to bring the volume to 1,000 cc. The suspension was thoroughly stirred and a sample was removed immediately for the determination of particles less than 0.005 mm. The procedure of Engle and Yoder was then followed in separat-

[4]The term "normal soil" as used in this paper refers to the parts of the field where plant growth is normal. It is not to be confused with the term as used in soil classification.

ing the remaining soil in the centrifuge tube. The percentages of the two portions of particles less than 0.005 mm were then added to obtain the total carbonate-free separate.

The mechanical analysis data by the method of Engle and Yoder and the percentages of carbonate-free separate less than 0.005 mm are presented in Table 1. The calcium carbonate contents and comparisons with percentages of particles less than 0.005 mm are shown in Table 2 The data of Table 1 show no consistent differences between the slick spots and normal soils. All of the soils were relatively high in the separate greater than 0.05 mm and low in the separate 0.05 to 0 005 mm. Except for field 1, the percentages of particles less than 0 005 mm by the two methods show about the same trends. The percentages of carbonate-free particles less than 0.005 mm in the normal soils were higher than in the slick spots for the three depths of fields 1 and 4 and lower in the three depths of field 3. In field 2, the percentages of particles less than 0 005 mm in the first depth of the normal soil was equal to that of the slick spot, while in the second depth the slick spot was higher and in the third depth the normal soil was higher.

TABLE 1 *Mechanical analysis of "slick spots" and normal soils from four fields*

Depth, inches	Mechanical analysis by method of Engle and Yoder, %						Carbonate-free, %	
	>0 05 mm		0 05 0.005 mm		<0.005 mm		<0 005 mm	
	Normal	Slick	Normal	Slick	Normal	Slick	Normal	Slick
				Field 1				
0-3	53 6	50.8	15 0	16 3	31 4	32 9	20 1	17.4
3 10	53.5	48.9	11.4	13 3	35 1	37.8	18 7	17.0
10 16	40.8	24.1	12.4	8.6	46.8	67.3	19.3	14.3
				Field 2				
0 6	53.6	60 6	17.0	10.2	29 4	29.2	28.8	28.6
6 9	51 0	48.7	19.1	8.4	29.9	42.9	29 0	40.0
9 15	34.1	43.5	15.2	12.6	50.7	43 9	49 4	37.2
				Field 3				
0 8	74.5	72.0	9.6	7.9	15.9	20.1	17.3	19.1
8 15	75 6	49.7	10.0	9.6	14.4	40.7	16 3	25.3
15 22	51 9	36.2	14.2	11.2	33.9	52.7	21.5	27.4
				Field 4				
0 7	61 4	73.9	17.3	10.8	21.3	15.3	17 9	14.8
7 13	59.7	71.5	14.2	10.8	26.2	17.7	20.8	14.5
13 19	41.3	64.0	15.4	9.7	43.3	27.3	23.5	17.5

A study of columns 2 and 5 in Table 2 shows that there is no consistent difference between calcium carbonate contents of slick spots and normal soils. In the third depth of fields 1 and 2, the slick spots contained a much greater percentage of calcium carbonate than the normal soils, but there was no difference in the other two depths. In

field 3 the slick spots contained a higher percentage of calcium carbonate in all three depths while the reverse was true for field 4.

TABLE 2 *Calcium carbonate content, percentage of particles less than 0.005 mm by the Engle and Yoder method, and the sum of the percentages of calcium carbonate and carbonate-free particles less than 0 005 mm for slick spots and normal soils from four fields*

	Normal soil			Slick spots		
Depth inches	Calcium carbonate, %	<0 005 mm (Engle & Yoder), %	Carbonate-free particles <0 005 mm + calcium carbonate %	Calcium carbonate, %	<0 005 mm (Engle & Yoder), %	Carbonate free particles <0 005 mm + calcium carbonate, %
			Field 1			
0 3	14 0	31 4	34 1	14 7	32 9	32 1
3 10	17 6	35 1	36 3	17 8	37 8	34 8
10 16	27 2	46 8	46 5	45 9	67 3	60 2
			Field 2			
0 6	0 3	29 4	29 1	0 5	29 2	29 1
6 9	0 3	29 9	29 3	0 4	42 9	40 4
9 15	0 3	50 7	49 7	9 6	43 9	46 8
			Field 3			
0 8	0 9	15 9	18 2	1 8	20 1	20 9
8 15	1 9	14 4	18 2	11 7	40 7	37 0
15 22	17 2	33 9	38 7	18 2	52 7	45 6
			Field 4			
0 7	6 0	21 3	23 9	4 1	15 3	18 9
7 13	9 7	26 2	30 5	4 9	17 7	19 5
13 19	18 1	43 3	41 6	12 8	27 3	30 3

The data of columns 3, 4, 6, and 7 in Table 2 show the sum of the percentages of carbonate-free particles less than 0 005 mm to be approximately equal to the percentage of particles less than 0 005 mm as determined by the method of Engle and Yoder Apparently the carbonate exists in these soils largely in a finely divided state

EXCHANGEABLE BASES AND BASE EXCHANGE CAPACITY

The procedure used in studying the base exchange characteristics of slick spots was essentially the same as that developed by Magistad and Burgess (9) for calcareous soils, except the several leachings and washings were performed by the method described by Russel (12)

The first leaching to remove soluble salts was made with 500 cc of 50% methyl alcohol. The second leaching to remove the exchangeable bases was made with 500 cc of 0.1 normal barium chloride in 90% methyl alcohol The third leaching to saturate with ammonium ions for base exchange capacity was made with 250 cc neutral normal ammonium acetate The excess ammonium salts was removed with 250 cc of 50% methyl alcohol. Excess barium in the leachate was precipitated by 3 N potassium chromate from a warm solution. Calcium was precipitated as the oxalate and determined volumetrically by potassium permanganate

titration. Magnesium was determined gravimetrically as the pyrophosphate. Replaced ammonium was determined by distillation from Kjeldahl flasks, using calcium oxide as the displacing base. Replaceable sodium and potassium[5] were not determined directly but were computed collectively as the difference between the base exchange capacity and the sum of the exchangeable calcium and magnesium. The pH of the soils was determined by the Coleman pH Electrometer.

The data presented in Table 3 show that the slick spots are higher in exchangeable sodium and potassium than their corresponding normal soils. There are, however, variations in the base exchange properties of slick spots and normal soils from the different fields studied. The slick spot of field 1 has a very low content of exchangeable sodium and potassium in the first layer, but the two lower layers are relatively high. In contrast, the slick spots of fields 2, 3, and 4 have a high content of exchangeable sodium and potassium in the three depths studied. The normal soils differ even more. In field 1 the normal soil has no exchangeable sodium and potassium in the surface depth, but it has an appreciable quantity in the lower depth. The normal soil of field 4 has a low content of exchangeable sodium

TABLE 3.—*Exchange capacity, exchangeable calcium, magnesium, and sodium and potassium of slick spots and normal soils from four fields*

Depth, inches	Exchange capacity, M.E. /100 grams		Exchangeable Ca, M.E./100 grams		Exchangeable Mg, M.E /100 grams		Exchangeable Na+K (by difference), M E., 100 grams	
	Normal	Slick	Normal	Slick	Normal	Slick	Normal	Slick
				Field 1				
0–3	13.68	13.33	10.27	9.55	3.90	3 57	0.00	0.21
3–10	14.43	15.40	8.83	6.25	3.66	4.32	1.94	4.87
10–16	16.10	14.80	6.70	4.52	4.93	2.29	4.47	7.99
				Field 2				
0 6	17.70	16.60	5.63	4.03	6.55	5.32	5.52	7.25
6–9	16.50	22.30	4.33	3.49	7.10	7.79	5.07	11.02
9–15	31 53	20.92	10.70	4.80	12.75	7.68	8 08	8.44
				Field 3				
0–8	14.67	15.64	7.70	7.29	1.96	1.28	5.01	7.07
8–15	12.35	17.92	5.58	3.99	1.96	0.91	4.81	13.02
15–22	17.12	23.17	9.61	4.19	4.23	1.06	3.28	17.92
				Field 4				
0–7	13 89	13.11	10.14	5.31	1.33	1.57	2.42	6.23
7–13	12.52	11.51	10.37	1.67	1.59	1.06	0.56	8.78
13–19	15.21	13.07	11.14	1.35	2.86	2.14	1.21	9.58

[5]The authors recognize the desirability of methods for the direct determinations of sodium and potassium. However, it has been the experience of the authors that the direct determinations of sodium and potassium displaced by a barium chloride solution are subject to considerable error. On the other hand, satisfactory determinations of calcium and magnesium may be made. Therefore, the computation of sodium and potassium by difference may be expected to be about as accurate as their direct determination.

and potassium in the three depths while fields 2 and 3 are relatively high in the three depths. Field 2 differs from the others in that the soils are higher in exchangeable magnesium than in exchangeable calcium.

Data on the degree of saturation of the exchange complex by sodium and potassium together with pH determinations and calcium carbonate contents are shown in Table 4. There appears to be a fairly close relationship between the pH of the slick spots and normal soils and their respective percentages of exchangeable monovalent ions and calcium carbonate. Minimum pH values of 7.6 to 7.9 occur in the layers of normal soils which contain 6% or less of calcium carbonate and where the degrees of saturation with exchangeable sodium and potassium range between 15 and 35%. Maximum pH values of 9.3 to 9.7 occur in layers of the slick spots which contain 5 to 45% calcium carbonate and where the degrees of saturation with exchangeable sodium and potassium are greater than 50%. In the pH range of 8.0 to 8.4 there are two groups of conditions. The soils in one group contain 10 to 20% calcium carbonate, but the saturation with exchangeable sodium and potassium is less than 20%. The soils of the other group contain less than 4% calcium carbonate, but the saturation with exchangeable sodium and potassium is between 40 and 50%. Four soil layers have pH values between 8.5 and 9.2. Two of these having pH values of 9.0 and 9.1 contain appreciable quantities of calcium carbonate with 28 and 40% saturation with sodium and potassium. According to their contents of calcium carbonate and exchangeable sodium and potassium, the other two soils having pH values of 8.6 and 8.8 would be expected to have pH values of approxi-

TABLE 4.—*Percentage saturation with sodium and potassium, pH, and percentage calcium carbonate of slick spots and normal soils from four fields.*

Depth, inches	Saturation with Na+K, %		pH		Calcium carbonate, %	
	Normal	Slick	Normal	Slick	Normal	Slick
			Field 1			
0-3	0.0	1.6	8.4	8.4	14.0	14.7
3-10	13.4	31.4	8.6	9.1	17.6	17.8
10-16	27.8	54.0	9.0	9.5	27.2	45.9
			Field 2			
0-6	31.2	44.7	7.7	8.4	0.3	0.5
6-9	30.7	49.4	7.9	8.8	0.3	0.4
9-15	25.6	40.3	7.8	9.1	0.3	9.6
			Field 3			
0-8	34.2	45.2	7.7	8.4	0.9	1.8
8-15	38.9	72.7	8.2	9.5	1.9	11.7
15-22	19.2	77.4	8.2	9.3	17.2	18.2
			Field 4			
0-7	17.4	47.5	7.6	8.2	6.0	4.1
7-13	4.5	76.3	8.0	9.4	9.7	4.9
13-19	8.0	73.3	8.3	9.7	18.1	12.8

mately 8.4. However, small discrepancies may be due to a difference in the ratio of sodium to potassium as well as to errors in the pH determinations.

DISCUSSION

Slick spots vary so much in their adaptability for plant growth and in other characteristics that it is difficult to select any one factor as being responsible for their poor condition. The results reported in this paper indicate that the poor physical condition of slick spots is due mainly to the presence of exchangeable sodium and potassium. Observations of physical characteristics and other properties both in the field and laboratory make it logical to assume that sodium is largely responsible. In the field it was noticed that certain layers in slick spots containing large quantities of calcium carbonate and sand were extremely hard and impervious to water. It was found that the clay from these layers was highly saturated with monovalent ions. Apparently the mixture of dispersed clay, calcium carbonate, and sand resulted in the formation of a concrete-like mass In comparison, those layers that contained clay highly saturated with exchangeable monovalent ions but with low quantities of calcium carbonate did not appear so dense and refractory. Those layers in the normal soil that contained large quantities of calcium carbonate and a high degree of saturation of the clay with calcium and magnesium were not impervious. The influence of calcium carbonate on the physical properties of the soil appears to depend upon the exchangeable ions associated with the clay. Of course the amount of clay present would also affect the physical condition of the soil.

The inability of plants to grow normally in slick spots may be due to the physical nature of the soil and to the high pH. It has been observed many times that plants growing on these spots wilt very soon after an irrigation while the plants growing on the normal soils have sufficient water for optimum growth. The irrigation water does not penetrate the slick spots readily even when the soil is in a loosened condition. The first addition of water puddles and compacts the soil so that water penetration is limited to a few inches. This puddled and compacted soil offers a poor physical medium for the growth of plants because of the low water supply and the poor aeration. In addition the slick spots have such a high pH that plants may be unable to absorb nutrients. Breazeale and McGeorge (1) have shown that plants are unable to absorb phosphate or nitrate ions readily at a pH above 7.6. In the calcareous slick spots phosphorus and iron compounds are relatively insoluble. The lack of available calcium may be serious in non-calcareous slick spots. Ratner (11) suggested that the death of plants in soils high in exchangeable sodium may be due to the breaking down of the calcium regime. Plants would be expected to obtain sufficient calcium in the calcareous slick spots, but some plants may be unable to utilize calcium at a high pH.

SUMMARY

Mechanical analysis, carbonates, pH, exchange capacity, exchangeable calcium, exchangeable magnesium, exchangeable sodium and

potassium, and percentage of saturation with sodium and potassium are reported for slick spots and normal soils from four fields in the North Platte and Platte valleys of Nebraska. The data may be summarized as follows:

1. There was no consistent difference found between the calcium carbonate content of the percentage of particles less than 0.005 mm of slick spots and normal soils. In the mechanical analysis procedure of Engle and Yoder (4) most of the calcium carbonate was analyzed in the separate less than 0.005 mm.

2. The slick spots were consistently higher than the normal soils in percentage of saturation with sodium and potassium. The poor physical properties of the slick spots was attributed to the higher content of exchangeable sodium and potassium.

3. A close relationship is shown between the pH of the slick spots and normal soils and their respective percentages of exchangeable monovalent ions and calcium carbonate.

LITERATURE CITED

1. Breazeale, J. F., and McGeorge, W. T. Nutritional disorders in alkaline soils are caused by deficiency of carbon dioxide. Ariz. Agr. Exp Sta. Tech. Bul. 41. 1932.
2. Burgess, P. S. Alkali soil studies and methods of reclamation. Ariz. Agr. Exp. Sta. Bul. 123. 1928.
3. Catlin, C. N., and Vinson, A. E. Treatment of black alkali with gypsum. Ariz. Agr. Exp. Sta. Bul. 102. 1925.
4. Engle, E. B., and Yoder, D. R. Application of the Robinson method to the determination of clay. Jour. Amer. Soc. Agron., 18:1016–1025. 1926.
5. Gardner, Robert, Whitney, Robert S., and Kezer, Alvin. Slick spots in western Colorado soils. Colo. Agr. Exp. Sta. Tech. Bul. 20. 1937.
6. Hayes, F. A., Condra, G. E., and Layton, M. H. Soil survey of Dawson County, Nebraska. Field Operations U. S. Bur. Soils, 1922. 1925.
7. ————, Hawker H. W., Davis, M. D., and Seabury, V. H. Soil survey of Morrill County, Nebraska. Field Operations, U. S. Bur. Soils, 1917. 1920.
8. Isaak, Philip. The nature of slick soil in southern Idaho. Soil Science, 37:157–165. 1930.
9. Magistad, O. C., and Burgess, P. S. The use of alcoholic salt solutions for the determination of replaceable bases in calcareous soils. Ariz. Agr. Exp. Sta. Tech. Bul. 20. 1928.
10. Peterson, P. P. The "slick spots" of middle western Idaho with suggestions for their elimination. Idaho Agr. Exp. Sta. Bul. 114. 1919.
11. Ratner, E. I. The influence of exchangeable sodium in the soil on its properties as a medium for plant growth. Sci. Res. Inst. for Fertilizers, Moscow, U.S.S.R. Soil Science, 40:459–469. 1935.
12. Russel, J. C. A method for the continuous automatic extraction of soils. Soil Science, 36:447–450. 1933.
13. Skinner, L. T., and Beck, M. W. Soil survey of Scottsbluff County, Nebraska. Field Operations, U. S. Bur. Soils, 1913. 1915.

A COMPARISON BETWEEN YIELDS CALCULATED FROM THE GRAIN-STRAW RATIO AND THOSE CALCULATED FROM SMALL CUT-OUT AREAS[1]

J. F. Davis[2]

In order to insure a valid interpretation of field plat data the value of correct statistical analysis of the results is practically universally recognized. With the use of statistical methods requiring more replicates the number of field plats is materially increased and the labor involved in the care of these extra plats is correspondingly greater. Therefore, any means that results in a saving of time and which does not lessen the accuracy of the data obtained would be a very desirable addition in field work operations.

In a recent paper,[3] a plan was suggested in which the yields of experimental plats can be accurately determined from the grain-straw ratio.[4] If plat yields determined from the grain-straw ratio are sufficiently reliable, the hand labor involved in cutting out small areas in the plat can be eliminated, thus materially facilitating harvesting operations. This proposed method of plat yield determination would apply primarily to plats with sufficient area so that a binder can be used in harvesting. Plats with an area of 1/30 acre can be harvested in this way. Also, this size of plat is large enough to allow for the discarding of a portion of the crop to eliminate border effects. In order to simulate field conditions and farming practices as closely as possible in carrying out an experiment, a program that allows for that size and shape of plat which makes practical the use of ordinary machinery is very desirable. The relationship of fertilizer placement to growth response of a crop makes it extremely important that results secured from an experiment carried out under one set of conditions are not allowed to refer to similar work carried out under different conditions. For example, in fertilizer studies with small grains it is illogical to assume that fertilizer applied broadcast over a plat is necessarily going to produce the same response as it would if applied with a grain drill with fertilizer attachment, the usual method employed by Michigan farmers. It would appear, then, in this particular case that the plat should be large enough to allow the use of a grain drill. However, this increases the area and requires more labor. Past experience has shown that one of the most important limiting factors in small grain fertilizer experiments is the labor involved at

[1] Contribution from the Soils Section of the Michigan Agricultural Experiment Station, Michigan State College, East Lansing, Mich. A portion of a thesis submitted to the faculty of Michigan State College in partial fulfilment for the degree of master of science. Authorized for publication by the Director as Journal Article No. 352 n.s. of the Michigan Experiment Station. Received for publication July 5, 1939.

[2] Assistant in Soils. The writer is indebted to Professor W. D. Baten for assistance in the preparation of this manuscript.

[3] Davis, J. F., and Cook, R. L. A comparison between actual plat yields and those calculated from grain-straw ratios. Proc. Soil Sci. Soc. Amer., 1:265–268. 1937.

[4] The term grain-straw ratio refers to the relationship existing between the grain weight and the weight of the unthreshed bundles.

harvesting time. It is for this type of work that determining plat yields with a minimum of work would prove advantageous in the field work program.

Any method then that reduces the hand labor involved and at the same time is sufficiently accurate to give dependable results, is very desirable. In this paper a comparison between yields calculated by this method and yields secured by the usual method of cutting out small areas from the plat will be made in order to determine which method gives results most comparable to those obtained from threshing the entire plat.

PROCEDURE

The comparisons between the different methods of harvest were made on a series of 16 oat plats. These plats were 14 by 150 feet in size, consisting of 22 rows 7 inches in width, representing one round with an 11-disc grain drill, the type extensively used in the planting of field plats at the Michigan Experiment Station. Six areas, 6 rows by 16½ feet, were cut out of each plat with a hand sickle and each area was labeled to denote the order in which the areas were cut. Since from the appearance of the plats very little difference could be observed in the growth of grain in different portions of an individual plat, the cut-out areas were taken alternately from either side of the plat. This constituted a total area of 6 rows by 99 feet that was cut out of each plat with the hand sickle. The ends of each plat were cut off with the binder, thus leaving approximately 135 feet to be harvested from the original 150 foot plat.

After the cut-out areas were removed and the bundles tied and labeled, the remainder of the plat was cut with the binder. The area cut off the end of each plat allowed for sufficient space for the binder to clean out between any two plats in adjoining blocks. The bundles from each plat were shocked on the plat and when dry were weighed and threshed. During the threshing operations five bundles were selected at random and threshed individually as were the areas cut out with the hand sickle. All the bundles from the plat were then threshed to get the actual yield of each plat. Yields based on one, two, three, four, five, and six cut-out areas were then computed for each plat. In addition, yields for each plat were calculated from the grain-straw ratios and the total bundle weights. This was done for one, two, three, four, and five bundles selected at threshing time.

From the six "cut-out" areas one area was selected at random from each plat and a comparison made between the results thus obtained and those obtained from the systematically selected areas. From the data, correlation coefficients, corresponding "Z" values, the lines of best fit, standard errors of estimate, and the standard errors of estimate from the line Y = X were calculated.

DISCUSSION

CORRELATION COEFFICIENTS

The correlation coefficients obtained in the study are recorded in Table 1. The correlation coefficients represent the relationship between yields calculated by the various methods used in harvesting and the yields secured from threshing the entire plat. The correlation coefficients in each case were found to be significant and ranged from .7500 for the low-yielding cut-out area to .9635 for the comparison

between the actual plat yield and the yield calculated from five threshed bundles.

TABLE 1.—*Correlation coefficients, corresponding Z values, and mean differences of Z values of five bundles threshed and other methods of harvest.*

Methods of harvest	r*	Z	Mean difference
5 bundles threshed	.9635	1 9935	——— -
4 bundles threshed	.9632	1 9894	.0041 ±.3922
3 bundles threshed	.9456	1.7857	.2078 ±.3922
2 bundles threshed	9203	1.5910	.4025 ±.3922
1 bundle threshed	9018	1.4819	.5116 ±.3922
6 areas threshed	.8462	1 2429	.7506 ± 3922
5 areas threshed	.8487	1.2516	.7419 ±.3922
4 areas threshed	.8336	1.2000	.7935 ± 3922
3 areas threshed	8773	1.3642	6293 ± 3922
2 areas threshed	7819	1.0503	.9432 ± 3922
1 area threshed	7500	9730	1 0205 ± 3922

*The 5% point = 6226

By examining Fisher's Table V A. (page 212),[5] it is found that all the correlation coefficients are significant It can readily be noted that the correlation coefficients for the one-, two-, three-, four-, and five-bundle comparisons were considerably higher than any of the coefficients from the cut-out area comparisons. The inference, then, is that yields obtained from weight relationships more nearly approach the actual plat yields than do yields based on area relationships. However, due to the small number of comparisons available, the "r" values were changed to "Z" values in order that a more nearly correct evaluation of the data could be made

VALUE OF Z

The magnitudes of the Z values bring out more clearly the differences existing between the various methods of harvest. However, the only significant differences in the "Z" values are in the comparisons between one and two cut-out areas and the five bundles selected at harvest time. The difference between the "Z" value for the four cut-out areas and that from the five bundles closely approaches significance. It should be mentioned here that the standard error of a "Z" value is calculated as the reciprocal of the square root of a number three less than the number of items. It can easily be seen, then, that with a "Z" value calculated from data in which the number of items is necessarily limited the corresponding standard error is relatively large as compared to a similar "Z" value obtained from a large number of items. In previous work,[6] it was found that "Z" values obtained from similar data but with more replicates showed significant differences. It seems logical to assume that significant differences would actually exist between yields based on five and six cut-out areas and yields secured from the weight relationship of five bundles and the entire plat.

[5]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 6. 1936.
[6]See footnote 3.

REGRESSION LINES

The regression lines recorded in Table 2 are derived from the relationship existing between actual plat yields and yields estimated from the various harvesting methods. These lines point out very clearly the comparative degree of closeness of fit to the line Y = X, a line denoting unit changes in X and Y values. The fact that the regression lines secured from the weight relationships are very close to the line Y = X and in the case of the "three bundle" method of harvest practically coincident with it and in contrast all regression lines secured from the area methods of harvest are rather widely divergent from the line Y = X, show the superiority of a weight relationship method of harvest. Figs. 1 and 2 further illustrate the fact that the weight relationship method of harvest gives yields nearer to actual plat yields than does the area method.

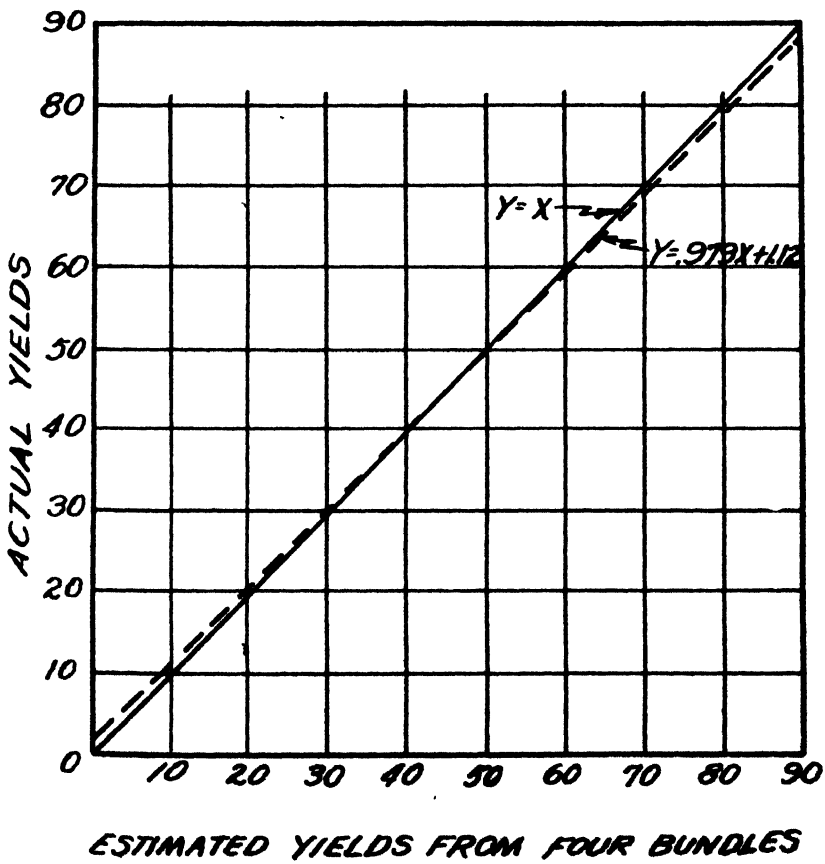

FIG. 1.—A comparison of the regression line and the line Y = X estimated from bundle yields.

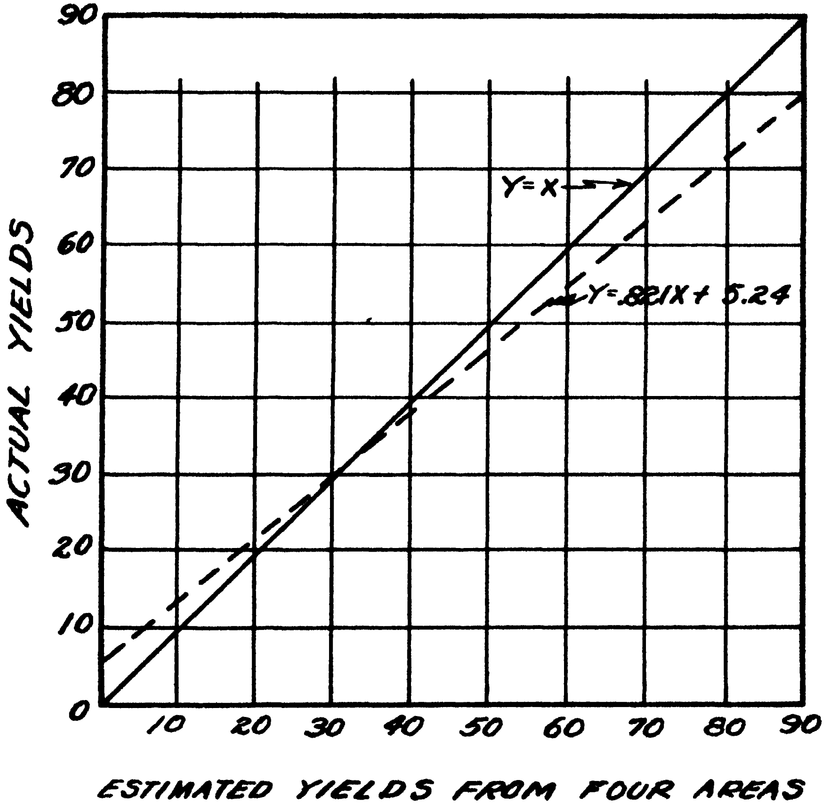

FIG 2 —A comparison of the regression line and the line Y = X estimated from area yields

TABLE 2 — *Regression lines and standard errors of estimate and errors of estimate from the line Y = X*

Methods of harvest	Regression lines	Standard errors of estimate	Errors of estimate from line Y = X
5 bundles threshed	y = 970x+ 1 40	2 360	2 401
4 bundles threshed	ȳ = 979x+ 1 12	2 373	2 412
3 bundles threshed	ȳ = 1 00x + 0 14	2 869	2 840
2 bundles threshed	ȳ = 953x+ 3 15	3 453	3 534
1 bundle threshed	y = 930x+ 3 75	3 816	3 920
6 areas threshed	y = 783x+ 8 57	4 700	7 630
5 areas threshed	ȳ = 782x+ 8 50	4 663	7 729
4 areas threshed	ȳ = 821x+ 5 24	4 785	8 55
3 areas threshed	ȳ = 750x+10 38	4 230	7 857
2 areas threshed	ȳ = 601x+21 04	5 494	8 265
1 area threshed	ȳ = 610x+19 37	5 832	9 402

STANDARD ERRORS OF ESTIMATE AND ERRORS OF ESTIMATE FROM THE LINE Y = X

The standard errors of estimate from the regression lines found in Table 2 indicate again that the weight relationship methods of harvest

give yields that compare more closely to actual yields than do yields secured from the area methods of harvest. When the yields are estimated from five bundles the standard error of estimate is 2.36 bushels. As the number of bundles threshed decreases the standard error of estimate consistently increases to 3.82 bushels for yields based on one bundle. The standard errors of estimate for the area methods are greater, ranging from 4.70 bushels for six "cut-out" areas to 5.832 bushels for one "cut-out" area. It should be noted the error for six "cut-out" areas is approximately 0.9 bushel greater than for one bundle. Two advantages, then, are found in favor of cutting the grain with the binder. Not only do the yields conform more closely to the actual plat yields, but the amount of labor involved in harvesting is also materially lessened.

A more logical comparison can be made if errors are calculated from the line Y = X since this line represents perfect agreement with actual plat yields. When these errors are calculated it serves to accentuate the differences between the harvesting methods. For the "bundle" method of harvest this value varies from 2.40 bushels to 3.92 bushels and for the area methods from 7.63 bushels to 9.40 bushels, showing again the superiority of the bundle method of harvest over the area method. Referring to the "Z" values and the "t" values in Table 3, calculated to show the significant differences between the standard errors both from the lines of best fit and the line Y = X, it is found in all cases at the 5% point that the yields based on five threshed bundles are significantly better than yields based on one bundle threshed or any yields calculated from small cut-out areas. Also, the yields from the five threshed bundles are significantly different than any yields secured from area methods of harvest at the 1% point, indicating again that yields estimated from weight relation-

TABLE 3.—*Z values and t values for differences between standard errors of estimate and Z values for differences between errors from the line Y = X of five threshed bundles and other methods of harvest.*

Method of harvest	Z value for errors of the line Y = X*	Z values of standard errors of estimate	t values of standard errors of estimates†
4 bundles threshed	.004	.005	.031
3 bundles threshed	.168	.195	1.092
2 bundles threshed	.387	.380	1.133
1 bundle threshed	.490	.480	2.588
6 areas threshed	1.156	.689	3.551
5 areas threshed	1.168	.680	3.516
4 areas threshed	1.269	.707	3.624
3 areas threshed	1.185	.583	3.076
2 areas threshed	1.236	.845	4.178
1 area threshed	1.365	.904	4.553

Z (5% point) .459
Z (1% point) .659
t (5% point) 2.048
t (1% point) 2.763

$$*Z = \tfrac{1}{2} \log_e \frac{(\sigma \text{ e of line } Y = X \text{ of treatment compared})}{(\sigma \text{ e of line } Y = X \text{ of 5 bundles threshed })}.$$

†The t values were calculated from the following formula: $t = \dfrac{\sigma e_1 - \sigma e_2}{\dfrac{S}{\sqrt{2N}}}$. This formula was derived by Professor W. D. Baten, who has not yet published his findings.

ships are closer to the actual yields than when the yields are secured from "cut-out" areas. No significant differences were found between yields based on five threshed bundles and yields obtained from four, three, or two threshed bundles, indicating that probably yields based on two or three threshed bundles are nearly as reliable as those secured from five bundles.

Likewise, according to these data, increasing the number of "cut-out" areas would not materially increase the reliability of the results if yields are to be calculated from small areas cut out by hand It is also very interesting to note that the "Z" test and the "t" test for the comparisons of the standard errors of estimate between the results from five bundles threshed and other methods of harvest show the same degree of significance in every case. The differences that are significant at the 5% point and the 1% point for the "Z" values are also significant according to the "t" test applied

The main question to be considered in any work dealing with a comparison of methods is whether in using one method the estimated results vary far enough from the actual yields of the plats to give erroneous conclusions. For this reason Table 4 is presented

An examination of Table 4 is quite convincing as to closer association of results with the actual when these results are estimated from weight relationships rather than from area relationships The argument is often made that comparative results between treatments are all that is required and the true yield of any plat is not essential providing the method of taking yields is essentially the same for all plats. The data indicate, however, that in order to get comparable results from a series of treatments a great deal of dependence would have to be placed upon compensating errors in order to arrive at results that would give this comparison between treatments if small "cut-out" areas are used. The significance of the results in Table 4 is demonstrated in the consideration of the magnitude of the errors from the line Y = X of the various harvesting methods. As previously stated, the larger this error becomes the more divergent the calculated plat yields are from the actual plat yields. This point has previously been discussed.

An examination of Table 5 indicated that the statistical constants obtained from a random area do not differ materially from the corresponding constants secured from a systematically selected area. In no case does a significant difference exist between constants derived from either method.

CONCLUSIONS

Yields obtained on three types of harvesting methods were secured from a series of oat plats. In the first method the entire plat was cut and threshed; in the second, yields were calculated from small areas cut-out with a hand sickle; while in the third, yields were obtained from the grain-straw ratio in a portion of the plat and the bundle weight of the entire plat.

Higher values for "r" and "Z" were obtained when actual plat yields were compared to yields calculated from weight relationships than from area relationships.

TABLE 4 —*Actual plat yields and plat yields calculated by the various harvesting methods* *

Method of harvest	Plat No															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Entire plat yield	62.5	58.2	40.4	36.4	61.0	66.0	59.4	65.6	57.7	57.3	66.1	63.0	55.8	60.7	65.5	59.6
5 bundles threshed	64.6	57.1	43.8	37.4	67.7	64.4	59.1	66.6	55.7	54.8	66.5	63.1	54.7	59.9	66.6	58.8
4 bundles threshed	62.7	57.6	43.6	37.4	67.7	64.4	59.3	68.1	55.7	55.1	65.4	62.7	53.4	59.9	65.2	59.2
3 bundles threshed	61.6	57.9	44.0	37.9	68.5	64.1	58.5	67.0	55.1	55.0	64.2	61.3	54.2	58.1	64.0	61.6
2 bundles threshed	62.0	56.6	45.5	36.9	67.7	63.6	54.5	68.2	52.6	56.3	62.2	65.0	55.9	56.6	64.8	60.5
1 bundle threshed	59.3	59.0	46.4	38.5	66.5	67.5	55.1	64.5	53.4	54.1	70.4	67.4	59.0	56.9	61.5	61.7
6 areas threshed	70.7	60.5	51.9	40.3	60.7	70.1	69.3	62.3	61.7	59.3	75.2	68.2	62.3	59.5	72.7	75.8
5 areas threshed	69.1	61.3	51.2	39.6	61.1	69.8	71.9	61.5	64.4	58.9	75.7	68.1	62.5	59.6	73.5	73.5
4 areas threshed	74.3	60.7	53.6	42.7	59.8	69.3	64.5	65.4	63.6	65.1	76.9	67.2	62.8	61.3	74.3	76.0
3 areas threshed	71.5	62.1	51.5	38.9	60.1	73.1	72.7	66.4	61.3	54.2	77.8	68.4	60.9	62.5	74.3	70.3
2 areas threshed	63.6	60.1	46.0	35.4	62.5	71.9	79.0	56.1	57.8	59.6	71.9	70.2	61.3	56.1	69.5	75.4
1 area threshed	70.7	69.5	58.9	35.4	56.6	75.4	64.8	66.0	74.3	50.7	70.7	69.5	57.8	61.3	74.3	69.5

*Yields are expressed in bushels per acre

TABLE 5.—*Comparison of results secured from one area selected at random and one area selected systematically.*

Statistical constant	Random selection	Systematic selection
r	.7230	.7500
Z	.9139	.9730
Mean difference, Z	1.0796±.3922	1.0205±.3922
Regression line	$\bar{y}=.587x+21.73$	$\bar{y}=.610x+19.37$
Standard error of estimate	5.885	5.832
Error of estimate from line Y=X	8.77	9.402
Difference in Z values from five bundles threshed and one area threshed	.948	.904

The regression lines obtained from the weight relationships compared more closely in all cases to the line Y=X than did the regression lines obtained from the area methods of calculating yields.

The standard errors of estimate and the errors of estimate from the line Y=X varied significantly between all area methods and the method in which the weight relationship of five bundles to the total grain and straw weight of the entire plat was used. The errors for the yields based on one bundle were significantly greater than the errors for yields based on five bundles. The magnitude of the errors in every case was considerably lower when yields were calculated from weight relationships than from the area methods.

The calculated yields varied progressively from the actual plat yield with the decrease in the number of bundles weighed and with the number of areas cut, but the yields from one bundle were closer to the actual plat yields than when yields were based on six areas.

From the data presented, it would appear that three bundles weighed from a plat of this particular size would give a very accurate estimate of the plat yields and would be the recommended number to use in yield estimation.

A harvested area as small as 1,000 square feet has been satisfactorily taken care of by this method.

When compared to the method of cutting out small areas, the grain-straw ratio method of harvest has the advantage of being more accurate and more efficient in the use of labor. An experiment consisting of 108 plats of oats was harvested in 4½ hours. Four men were required to do the work, two of the men were required to run the binder since the tractor did not have a power take-off. The amount of hand labor involved is materially lessened since the grain is cut with the binder.

THE DECOMPOSITION OF ORGANIC MATTER IN SOILS AT DIFFERENT INITIAL pH[1]

R. S. Dyal, F. B. Smith, and R. V. Allison[2]

ONE of the most important environmental conditions influencing the activities of soil micro-organisms is the hydrogen-ion concentration of the soil. It affects not only the rates of many of the physiological processes, the rates of growth and respiration, but also the types of organisms developing. The anion or the undissociated molecule of certain acids may be as effective as the hydrogen ion in increasing or decreasing microbiological action. However, there is considerable evidence which indicates that the beneficial effect of applications of lime to acid soils is due largely to the change in reaction brought about.

Numerous investigators have reported the effects of hydrogen-ion concentration on the growth or metabolic processes and the occurrence of specific organisms. Johnson (3)[3] in a study of the relationships between hydrogen ion, hydroxyl ion, and salt concentration and the growth of seven soil molds, obtained growth over a considerable range in pH. Itano (2) in a study of the effect of the initial hydrogen-ion concentration on the rate of proteolysis by *B. subtilis* in a peptone meat extract broth found the rate of growth to be most rapid at a pH of 6.66 and the rate of ammonia formation most rapid at pH 5.42 after 240 hours. Brooks (1) investigated the effect of hydrogen-ion concentration on the production of carbon dioxide by the tubercle bacillus and found no change in the production of carbon dioxide from pH 4.4 to pH 7.4 but there was a decrease in carbon dioxide production above and below these pH values.

Much of the earlier work in soils along these lines has been concerned with the effects of applications of lime on the numbers of bacteria or on the action of certain physiological groups. Waksman and Starkey (9) found that additions of lime stimulated the respiratory capacity of the soil and brought about an increase in the numbers of bacteria. Waksman and Heukelekian (8) found no correlation between the reaction of the soil and its cellulose decomposing power. However, it was explained that the fungi which are active cellulose decomposers grow well in acid soils. White, Holben, and Jeffries (10) have shown that corn starch was decomposed at about the same rate in acid as in alkaline soils, but that cellulose, manure, and cottonseed meal were decomposed more rapidly in limed than in acid soils. Lime added to acid soils stimulated carbon dioxide production and increased the numbers of micro-organisms. Smith and Brown (7) investigated the influence of substituted cations in the complex of Tama silt loam on the rate of decomposition of leguminous green manures and found that the rate of decomposition was least rapid in

[1]Contribution from the Department of Chemistry and Soils, University of Florida, Gainesville, Florida. Received for publication July 26, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 850.

the hydrogen saturated soil (pH 5.11) and most rapid in the magnesium soil (pH 6.43).

While many of the investigations reported give data in terms of hydrogen-ion concentration and some are directly related to the decomposition of organic matter, few of them were designed to study the effect of hydrogen-ion concentration on the decomposition of organic matter in soils. The purpose of the work reported here was to study the effect of reaction of the soil on the decomposition of various green plant materials in Norfolk loamy fine sand.

METHODS OF PROCEDURE

The soils of a series of reaction plats[4] of the Department of Chemistry and Soils of the Florida Agricultural Experiment Station were employed in this study. The treatments and pH of these soils are given in Table 1. A 2-quart sample of the top soil to a depth of 6 inches was taken from each of the plats Nos. 1, 2, 5, 8, 9, 10, and 12, air-dried, and screened through a 20-mesh sieve. Each soil was thoroughly mixed and the pH and water-holding capacity determined. Duplicate 250-gram portions of the soils were treated in 1-liter filter flasks with organic matter in four series as follows: Series I, green crotalaria; series II, green natal grass; series III, green natal grass and potassium nitrate; and series IV, green natal grass.

TABLE 1.—*The treatment, organic matter content and pH of soils of the reaction plats.*

Plat No.	Treatment in pounds per acre						pH	Organic matter* %
	Material	1926	1931	1935	1937	1938		
1	Sulfur	1,000	900	500	500	500	3.71	1.20
2	Sulfur	500	450	250	250	250	4.59	1.08
5	Limestone	2,000	900	1,000	1,000	1,000	6.33	0.86
8	Sulfur	500	450	250	250	250	4.26	1.02
9	No treatment	—	—	—	—	—	5.94	1.00
10	Limestone	1,000	450	500	500	500	6.50	0.94
12	Limestone	4,000	1,800	2,000	2,000	2,000	7.05	1.20

*Loss on ignition.

The *Crotalaria spectabilis* was taken from the Florida Agricultural Experiment Station farm when the plants were in the early bloom stage. The natal grass (*Tricholaena rosea*) was harvested at two stages of growth. In series II, designated as natal grass No. 1, the mature grass was used; and in series III and IV, designated as natal grass 2 and 3, respectively, the younger, vegetative grass was used. In series III sufficient potassium nitrate was added to each soil to make the total nitrogen content equal to that in series I where crotalaria was used.

The green plant materials were ground coarsely in a food chopper and mixed. One portion was then dried in an oven at 60° C. When the materials were dry they were ground in a Wiley mill and a subsample of each reduced in a Dreef pestle mill to pass a 60-mesh sieve. The subsamples were preserved for later analyses. The moisture content of the green plant materials was determined by drying in an electric oven for five hours at 110° C. Additions of the moist, green materials equal to 1% dry weight were made to the soils. The soil and the plant

[4]Established in 1926 by Dr. O. C. Bryan and now under the supervision of H. W. Winsor.

material were mixed thoroughly and the moisture content of the soils adjusted to 50% of the saturation capacity. The soils were incubated at room temperature and the carbon dioxide evolved was determined by aspiration with carbon dioxide-free air at regular intervals.

The apparatus used is shown in Fig. 1. A pressure pump was used to force air and sodium hydroxide into the bead tower. The air and sodium hydroxide ran

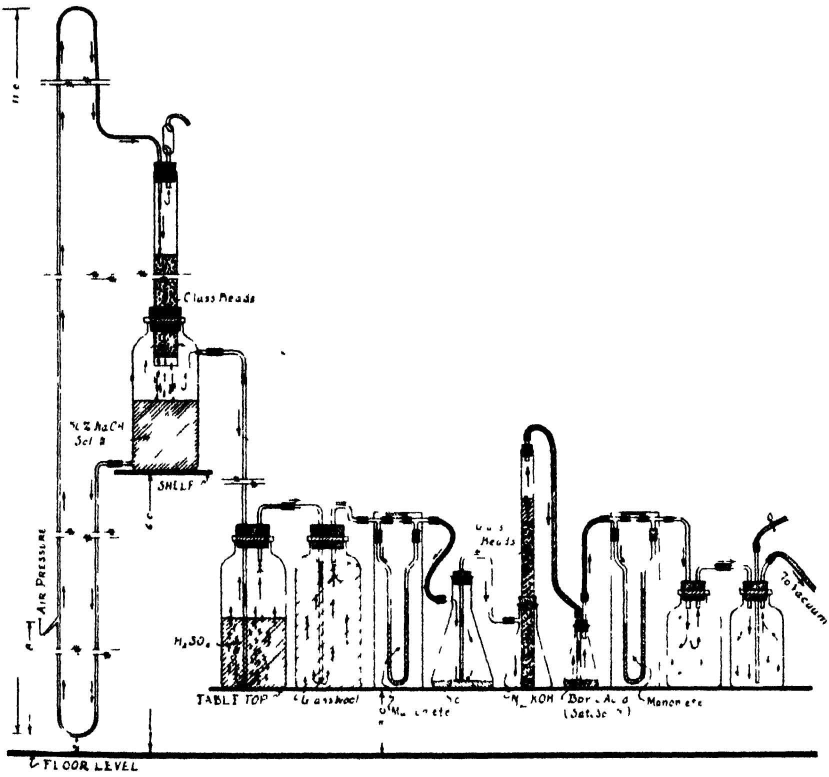

FIG. 1.—Apparatus used to determine carbon dioxide production.

down over the beads, freeing the air of carbon dioxide. The carbon dioxide-free air was then taken at atmospheric pressure by the vacuum from the top opening on the side of the sodium hydroxide bottle. Thus, the back pressure on the gas train was reduced to a minimum. The rate of aspiration was regulated at 4 liters per 30 minutes by means of manometers. The carbon dioxide was absorbed in ½ N potassium hydroxide. Barium chloride was used to precipitate the carbon dioxide and the excess potassium hydroxide was titrated with standard hydrochloric acid, using phenolphthalein as the indicator.

The experiment was discontinued when the amount of carbon dioxide produced during a given interval was about the same in the different soils. This was 20 days after the beginning of the experiment in series I, 28 days in series II, and 20 days in series III and IV.

After the carbon dioxide determinations were discontinued, the pH of the soils was determined by the quinhydrone electrode, and the moisture content by drying in the oven at 110° C for 5 hours.

The nitrification of crotalaria and the nitrification of ammonium sulfate in soils treated with natal grass were determined in a series of tumbler experiments. Duplicate 200-gram portions of the soils were treated with 4 grams of the finely ground plant materials and in the case of natal grass 30 milligrams of nitrogen as ammonium sulfate were added in solution. The moisture content of the soils was adjusted to 60% and maintained at that amount by frequent additions of distilled water. The tumblers were placed in the incubator at room temperature for 30 days after which the pH and nitrate content of the soils were determined. The nitrate nitrogen was determined by the phenoldisulfonic acid method.

A proximate analysis of the plant materials determining the ether-soluble fraction, sugars, starches, hemicellulose, and cellulose was made by a method proposed by Leukel, et al. (4). The lignin was determined by a modification of the Ritter, Seborg, and Mitchel (5) method. The nitrogen was determined by the Hibbard modification of the Gunning-Kjeldahl method, distilling the ammonia into boric acid as proposed by Scales and Harrison (6). The ash was determined by igniting to dull red heat in an electric muffle furnace.

RESULTS

CARBON DIOXIDE PRODUCTION

The total carbon dioxide production during the period of 20 days in soils treated with the green plant materials is shown in Fig. 2.

The data show that the amounts of carbon dioxide produced in the soils treated with crotalaria at pH values 3.71, 4.26, and 4.59 were of about the same magnitude and averaged slightly less than that of the soils at the higher pH values. The average difference in total carbon dioxide production in the two groups of soils was not great during the first few days of the experiment. However, after about four days there was a larger difference, indicating a somewhat more rapid decomposition of the crotalaria in the soils of a higher pH value. The pH values of the soils before and after treatment with crotalaria and incubation are presented in Table 2.

The pH of the soils treated with the crotalaria increased in every case, except in the soils at pH of 5.94, 6.50, and 7.05 in which cases there were slight decreases in pH. All of the untreated soils decreased in pH during the experiment, except the soil at pH 3.71 which increased to pH 3.76.

The decomposition of the mature natal grass increased with an increase in the pH of the soil from a pH of 3.71 to a pH of 6.50. The amount of decomposition of this material in the soil at pH 7.05 was slightly less than that in the soils at pH 6.33 and 6.50 but considerably greater than that in the soils at pH 5.94 or below. The amount of carbon dioxide produced in the soils at pH 4.59 or below was considerably less than the amount produced in the soils at pH 5.94 or above.

The pH of the soils treated with natal grass No. 1 increased in every case, except in the soil at pH 5.94 where it decreased to pH 5.75 (Table 2). The untreated soils in series II decreased in pH in every case.

The largest total production of carbon dioxide in the soils treated with natal grass and potassium nitrate was obtained in the soil at pH 7.05. The smallest total production of carbon dioxide and the least decomposition was obtained in the soils at pH 3.71. The rate of

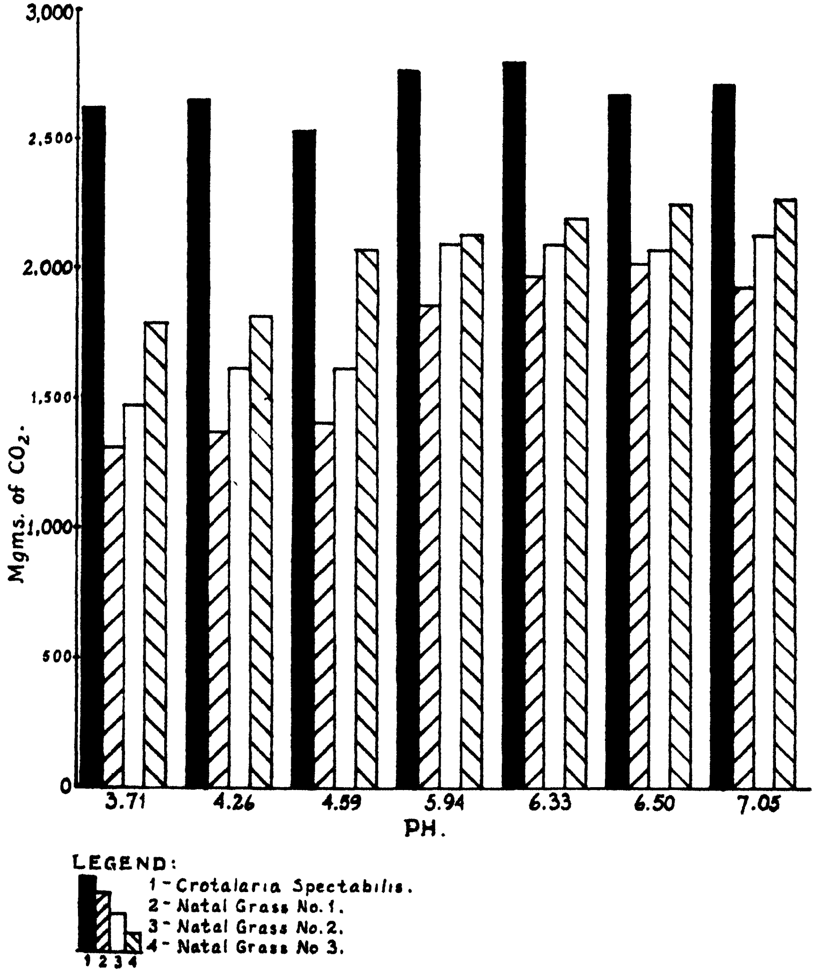

FIG. 2.—Carbon dioxide production in soils of different initial pH.

decomposition during the first three days of the experiment was about the same in all soils. However, after the fourth day the rate of decomposition was considerably more rapid in the soils at pH 5.94, 6.33, 6.50, and 7.05 than in the soils at pH 3.71, 4.26, and 4.59. The pH of the soils was decreased during the experiment where decomposition was most rapid, except in the case of the soil at pH 7.05 where it was increased (Table 2).

TABLE 2.—*The pH of soils before and after incubation.*

Soil No.	pH at beginning	pH at end of decomposition period: Crotalaria	pH at end of decomposition period: Natal grass No. 1	pH at end of decomposition period: Natal grass No. 2	pH at end of decomposition period: Natal grass No. 3	pH after nitrification: Crotalaria	pH after nitrification: Natal grass No. 1	pH after nitrification: Natal grass No. 1 +30 mgms N as $(NH_4)_2SO_4$	pH after nitrification: Natal grass No. 2	pH after nitrification: Natal grass No. 2 +30 mgms N as $(NH_4)_2SO_4$
1	3.71 a*	6.84	4.58	5.23	4.85	6.92	4.69	4.50	5.72	5.64
	b	3.76	3.68			4.06				
8	4.26 a	6.70	4.90	5.56	5.90	6.52	5.82	4.58	6.26	5.50
	b	4.19	3.92			4.46				
2	4.59 a	6.72	5.26	5.28	5.49	6.07	5.12	4.45	5.98	5.60
	b	4.10	4.09			4.49				
9	5.94 a	5.65	5.75	5.84	5.68	6.01	6.85	4.85	6.41	5.58
	b	4.98	4.67			5.25				
5	6.33 a	6.58	6.75	5.35	6.62	6.22	6.80	4.80	6.41	5.26
	b	5.64	5.83			6.71				
10	6.50 a	6.02	6.75	6.25	6.32	6.48	6.77	5.00	6.79	5.34
	b	5.96	5.94			6.38				
12	7.05 a	6.68	7.42	7.50	7.06	7.03	7.71	5.68	7.60	5.82
	b	6.80	6.56			7.12				

*a, soils treated with plant material; b, untreated soils.

The amount of decomposition of natal grass No. 3 increased with an increase in pH of the soil from pH 3.71 to pH 7.05. The average total decomposition at pH 3.71 to pH 4.59 was considerably less than the average decomposition in the soils at pH 5.94 to 7.05.

NITRIFICATION

The results of the nitrification experiments are presented in Table 3. The nitrate content of the untreated soils was relatively small in all cases but largest in the soil of pH 5.94 and smallest in the soil of pH 3.71. The nitrate content of the crotalaria-treated soils was higher at all pH values than that of any other treated soils, except that of the soil of pH 3.71 treated with natal grass and ammonium sulfate. The nitrification of crotalaria was considerably reduced in the soils of pH 3.71, 4.26, and 4.59. This was no doubt caused by the harmful effect of the acidity on the nitrifying organisms and, no doubt at least partly, by the types or kinds of micro-organisms decomposing the crotalaria in these soils. The maximum nitrification of the crotalaria was obtained in the soils of pH 6.33 The next largest nitrification of crotalaria was obtained in the soils of pH 5.94. In general, the nitrification of crotalaria was fairly high in all soils of pH 5.94 to 7.05 and relatively low in the soils of pH 3.71 to pH 4.59

TABLE 3 *The effect of crotalaria and natal grass on nitrification in Norfolk loamy fine sand at different pH values, p.p.m. of nitrate nitrogen*

pH of soil	Check	Crotalaria	Natal grass No. 1	Natal grass No. 1+30 mgm. N as $(NH_4)_2SO_4$	Natal grass No. 2	Natal grass No. 2+30 mgm. N as $(NH_4)_2SO_4$
3.71	Trace	Trace	0	0	0	6.76
4.26	3.44	26.68	0	0	0	5.23
4.59	4.06	24.53	0	Trace	Trace	5.30
5.94	4.22	80.52	0	Trace	Trace	6.00
6.33	3.52	100.00	0	28.56	Trace	41.30
6.50	2.66	65.97	0	3.68	3.80	21.50
7.05	2.85	66.63	0	18.02	Trace	22.14

The soils treated with natal grass No. 1 without additions of ammonium sulfate contained no nitrate. This was probably caused by the organisms utilizing all of the available nitrogen in the decomposition of the natal grass.

The soils treated with natal grass No. 1 plus 30 milligrams of nitrogen as ammonium sulfate contained no nitrates at pH 3.71 and 4.26 and the soils of pH 4.59 and 5.94 contained only a trace of nitrate nitrogen. The treated soil at pH 6.33 contained the largest amount of nitrate nitrogen of any soil in this series. The low nitrate content of the soils of pH below 6.33 may be explained by the kind of micro-organisms, the type of organic matter, and the acid condition of the soils.

The soils treated with natal grass No. 2 contained no nitrates at pH 3.71 and 4.26. All of the other treated soils contained only a trace of nitrates, except the soils at pH 6.50 which contained only 3.80 p.p.m.

All of the soils treated with natal grass No. 2 plus an addition of nitrogen as ammonium sulfate contained nitrates. The nitrification of ammonium sulfate in these soils was considerably less at pH values below 5.94 than at pH values of 6.33 to 7.05, the largest nitrification occurring in the soil at pH 6.33. These data seem to indicate a different type of decomposition and certainly different rates of decomposition at pH values of 5.94 or below from that obtained at the higher pH values. The pH of the soils in the nitrification experiments is presented in Table 2.

The data show that the pH of the soils treated with crotalaria was not changed as much as the pH of the soils treated with natal grass and ammonium sulfate. Apparently these changes in the pH of the soils during nitrification were caused by the nitric acid produced and in the case of the ammonium sulfate treated soil also to the residual sulfuric acid that developed during the process. In general, the greatest change in pH occurred in the soils in which nitrification was most pronounced.

ANALYSES OF PLANT MATERIALS

The analyses of the crotalaria and the natal grass used in these experiments are given in Table 4. All three plant materials contained relatively small percentages of the ether-soluble fraction, sugars, and starches. The mature natal grass (No. 1) contained larger amounts of the hemicellulose, cellulose, and lignin fractions and considerably less protein, ash constituents, and moisture than the crotalaria or the natal grass No. 2. The crotalaria contained the smallest percentage of lignin and the largest percentages of protein and water.

TABLE 4.—*Analyses of plant materials.*

Constituent	Crotalaria	Natal grass No. 1	Natal grass No. 2
Ether soluble	1.89	1.38	2.36
Total sugars	1.94	1.24	1.44
Starch	1.19	0.64	0.96
Hemicellulose	10.86	26.64	19.51
Cellulose	21.13	29.44	26.80
Lignin	14.47	18.26	17.75
Protein	16.65	3.97	9.38
Ash	6.27	5.65	10.61
Moisture	79.00	53.97	70.20

DISCUSSION OF RESULTS

There were slightly smaller amounts of carbon dioxide produced in the crotalaria-treated soils at pH 3.71, 4.26, and 4.59 than in the soils at pH 5.94, 6.33, 6.50, and 7.05. Possibly the reason why one soil decomposed the crotalaria about as readily as another was because of the increase in pH of the soils. The pH of the soils increased from 3.71, 4.26, and 4.59 at the beginning of the experiment to 6.84, 6.70, and 6.72 at the end of the incubation period. It is apparent, therefore, that the decomposition of the crotalaria in this soil was not taking place at pH 3.71.

The increase in the pH of these soils may be explained, at least partly, by free ammonia which might have been present and carbonic

acid. The carbonic acid might possibly increase the pH of the soil by the dilution of a stronger acid in a poorly buffered solution.

The natal grass No. 1 decomposed more readily in soils at pH values of 5.94, 6.33, 6.50, and 7.05 than in the soils at pH 3.71, 4.26, and 4.59.

The less rapid decomposition of the natal grass No. 1 in the soils of initial pH 3.71, 4 26, and 4.59 than in the soils at the higher pH values was undoubtedly caused by a detrimental effect of the increased acidity on the growth of the decay bacteria. Also the types of bacteria present in the soils of pH values 3.71, 4.26, and 4.59 were apparently different from those found in the soils at the higher pH values. The nitrogen content of the mature natal grass was not sufficient to permit the formation of nitrates as was revealed by the nitrification studies. The low nitrogen content and the relatively high content of hemicellulose, cellulose, and lignin were also factors in the slow decomposition of the natal grass.

The decomposition of natal grass No. 2 was more rapid in soils at pH values of 5.94, 6.33, and 7.05 at the beginning than in the soils at the lower pH values. The acidity of the soils at pH 3.71, 4.26, and 4.59 apparently inhibited the growth of the micro-organisms. The increase in pH of these soils was possibly caused by the potassium nitrate added to the soils. The micro-organisms used the nitrate and the potassium was left free to act as a basic residue to increase the pH of the soil.

The largest decomposition of natal grass No. 3 occurred in the soils of pH 7.05 and the least amount of decomposition was obtained in the soils at pH 3 71. This difference in the decomposition of the natal grass No. 3 may be attributed to the difference in numbers of micro-organisms in the soil and the retarding effect of the increased acidity at the lower pH values. Because of the low protein content of the natal grass the micro-organisms were not able to free any of the nitrogen as ammonia, consequently no nitrification of the natal grass occurred.

The total amount of carbon dioxide produced was largest in the soils treated with the crotalaria and smallest in the soil treated with the natal grass No. 1. There was a larger total production of carbon dioxide in the soils treated with the succulent natal grass No. 3 than in the soils treated with the more mature natal grass No. 1. There is no apparent reason why the natal grass No. 2 should have decomposed more slowly than the natal grass No 3, unless the potassium nitrate added proved toxic to the micro-organisms in the concentration used.

SUMMARY AND CONCLUSIONS

Four series of experiments were conducted on the decomposition of green crotalaria and green natal grass harvested at two different stages of growth in soils of varying degrees of acidity from pH 3.71 to pH 7.05. The results obtained may be summarized briefly as follows:

1. All plant materials decomposed more rapidly and more completely in soils at pH 5.94 to 7.05 than at pH 3.71 to 4.59.

2. The detrimental effect of acidity on decomposition was more pronounced in soils treated with natal grass than in soils treated with crotalaria.
3. The acidity of the soils treated with crotalaria was decreased markedly in the soils at low pH in the beginning of the experiment. This decrease in acidity of the soil was possibly caused by the liberation of ammonia or the dilution effect of carbonic acid or both. It can hardly be claimed that the full effect of the acidity of these soils on the decomposition of crotalaria was measured in these experiments.
4. The addition of nitrogen as potassium nitrate to the natal grass-treated soils in an amount sufficient to bring the total nitrogen content of these soils to that of the crotalaria-treated soils did not increase the decomposition of the natal grass.
5. The decreased nitrification in the soils at pH 3.71, 4.26, and 4.59 was undoubtedly brought about by the micro-organisms utilizing the ammonia in the decomposition of the carbonaceous materials and also partly by the detrimental effect of the increased acidity on the nitrifying bacteria. A deficiency of available calcium in the strongly acid soils could possibly have caused this decreased nitrification observed in the soils at low pH.
6. The plant materials containing the larger percentages of the hemicellulose, cellulose, and lignin fractions decomposed more slowly than those containing the smaller percentages of these constituents.

LITERATURE CITED

1. BROOKS, M. M. The effect of hydrogen-ion concentration on the production of carbon dioxide by the tubercle bacillus. Amer. Rev. Tuberculosis, 6:369 376. 1922.
2. ITANO, A. The relation of hydrogen-ion concentration of media to the proteolytic activity of *Bacillus subtilis*. Mass. Agr. Exp. Sta. Bul. 167. 1916.
3. JOHNSON, H. W. Relationships between hydrogen ion, hydroxyl ion, and salt concentration and the growth of seven soil molds. Ia. Agr. Exp. Sta. Res. Bul. 76. 1923.
4. LEUKEL, W. A., BARNETTE, R. M., and HESTER, J. B. Composition and nitrification studies on crotalaria striata. Soil Sci., 28:347-371. 1929.
5. RITTER, G. J., SEBORG, R. M., and MITCHELL, R. L. Factors affecting quantitative determination of lignin by 72 per cent sulfuric acid method. Ind. and Eng. Chem., Anal Ed., 4:202 204. 1932.
6. SCALES, F. M, and HARRISON, A. P. Boric acid modification of the Kjeldahl method for crop and soil analysis. Jour. Ind. and Eng. Chem., 12:350-352. 1920.
7. SMITH, F. B., and BROWN, P. E. Unpublished data. Iowa Agr. Exp. Sta., Ames, Iowa 1937.
8. WAKSMAN, S. A., and HEUKELEKIAN, O. Microbiological analysis of soil as an index of soil fertility: VIII. Decomposition of cellulose. Soil Sci., 17:280-284. 1924.
9. ——— and STARKEY, ROBERT L. Microbiological analysis of soil as an index of soil fertility: VII. Carbon dioxide evolution. Soil Sci., 17:141-161. 1924.
10. WHITE, J. W., HOLBEN, F. J., and JEFFRIES, C. D. Influence of soil acidity upon the decomposition of organic matter in soils. Soil Sci., 37:1-15. 1934.

MILLING, BAKING, AND CHEMICAL PROPERTIES OF COLORADO-GROWN MARQUIS AND KANRED WHEAT STORED 9 TO 17 YEARS[1]

D. W. ROBERTSON, C. C. FIFIELD, AND LAWRENCE ZELENY[2]

CURRENT interest in long-time storage of wheat suggests the need for information with respect to the relation between length of storage and quality. It is well known that any damage such as will affect the commercial grade is likely to affect the quality deleteriously, but information with respect to possible deterioration when wheat is stored dry and free from insect damage is decidedly deficient. Wheat from the 1921 and later crops stored under such conditions by the Colorado Agricultural Experiment Station for the purpose of studying the relation of age to viability appeared to afford an unusual opportunity to study this relation. Accordingly, samples of those lots were milled and baked in the Milling, Baking, and Chemical Laboratory of the Bureau of Agricultural Economics in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in 1938.[3] The purpose of this paper is to present such of the resulting data as will be of interest. Robertson and Lute[4] have reported on the germination of the samples and have given the pertinent facts regarding their storage.

MATERIALS AND METHODS

Briefly, the studies herein reported were limited to Marquis spring wheat grown under irrigation and Kanred winter wheat grown on fallow without irrigation. After threshing and cleaning, the grain was stored in 100-pound sacks in a dry, unheated room. The annual precipitation and average annual humidity at Fort Collins are given by Robertson and Lute[5] and the possible relation of these to storage is also discussed by these authors. The moisture content of the grain at time of storage was not determined but is believed to have been relatively low.

Samples of Marquis representing eight crops from the years 1921 to 1929 and of Kanred representing three crops from the years 1921, 1924, and 1929 were milled and the flour baked into bread.

The tempered wheats were milled on an Allis-Chalmers experimental flour mill provided with three pairs of break rolls and one pair of smooth rolls. (See U. S. Dept. of Agr. Tech. Bul. No. 197 for complete description of milling equipment and operative technic). Chemical tests (moisture, ash, and protein) were made by

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[1]Contribution from the Department of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication July 27, 1939.

[2]Agronomist, Colorado Agricultural Experiment Station, Associate Baking Technologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, and Associate Grain Technologist, Grain Division, Bureau of Agricultural Economics, respectively.

[3]Credit is due H. C. Fellows, J. F. Hayes, Elwood Hoffecker, Ray Weaver, B. E. Rothgeb, and M. H. Newstadt of the Milling, Baking, and Chemical Laboratory for making some of the determinations reported in this paper.

[4]ROBERTSON, D. W., and ANNA M. LUTE. Germination of seed of farm crops in Colorado after storage for various periods of years. Jour. Amer. Soc. Agron., 29:822–834. 1937.

[5]*Loc. cit.*

accepted and approved methods of the American Association of Cereal Chemists. Acidity was determined on the extracted fat constituents of the wheat by the method suggested by Zeleny and Coleman.[6] The fat acidity values are expressed in terms of the number of milligrams of potassium hydroxide required to neutralize the free fatty acids from 100 grams of wheat ascertained on a dry matter basis.

Bread baking tests were made by the straight dough method, employing the baking formula ingredients most commonly used by commercial bakers. For this purpose three formulas were employed, namely, (1) commercial, using 100 grams flour, 5.0 grams sugar, 1.5 grams salt, 2.0 grams yeast, 3.0 grams shortening, 4.0 grams dried skimmilk, and sufficient water to form a dough of proper consistency; (2) commercial-bromate, same as formula No. 1, plus 1 mg of potassium bromate; and (3) a second commercial formula the same as formula No. 1 except the amount of yeast was increased to 3.0%. The milling, baking, and chemical results are shown in Table 1. The loaves baked from Marquis are shown in Fig. 1 and those from Kanred in Fig. 2.

EXPERIMENTAL RESULTS

Good flour yields were obtained from all samples, none being less than 69.3% obtained from the 1925 Marquis, which can be accounted for by the low (57.8 pounds) test weight. None of the lots required special tempering treatment or special handling in the mill to secure optimum flour yields.

The protein content varied from 11.3% for Marquis harvested in 1925 to 14.4 and 14.5% for the 1921 and 1927 crops, respectively. Kanred ranged from 12.9 to 14.3%. None of the samples, with the possible exception of the 1925 Marquis, can be considered too low in protein for good bread.

Fat acidity values on Marquis ranged from 26.2 for the 1929 samples to 47.7 for the 1921 samples and on Kanred from 26.7 for the 1929 samples to 37.5 for the 1921 samples. Unquestionably, the higher fat acidity values on the 1921 samples indicate that some deterioration has taken place during the long storage period. It has been demonstrated[7] that fat acidity values range from less than 20 for freshly harvested sound wheat to 70 or more for badly deteriorated wheat and may be used as an approximate index of the degree of deterioration the wheat has undergone. Broadly speaking, while values of 50 or less are not ordinarily associated with impaired milling or baking quality of the freshly milled flour, preliminary evidence indicates that flour milled from wheat having acidity values of approximately 50 or more will deteriorate in baking quality during storage more rapidly than will flour from wheat of lower acidity.

Gassing power determinations made on the flour as an indication of the raw starch amylase or susceptible starch available for use during the fermentation period reveal marked differences for the lots harvested in different years. The 1921 and 1925 crops of Marquis were definitely superior in gassing power to those of 1923, 1927, or

[6]Zeleny, Lawrence, and Coleman, D. A. Acidity in cereal and cereal products, its determination and significance. Cereal Chem., 15:580–595. 1938.

[7]Zeleny, Lawrence. Unpublished data.

1929. For Kanred the values were highest in 1921 and lowest in 1929. It is not apparent from these data that long storage is associated with either an increase or decrease in gassing values.

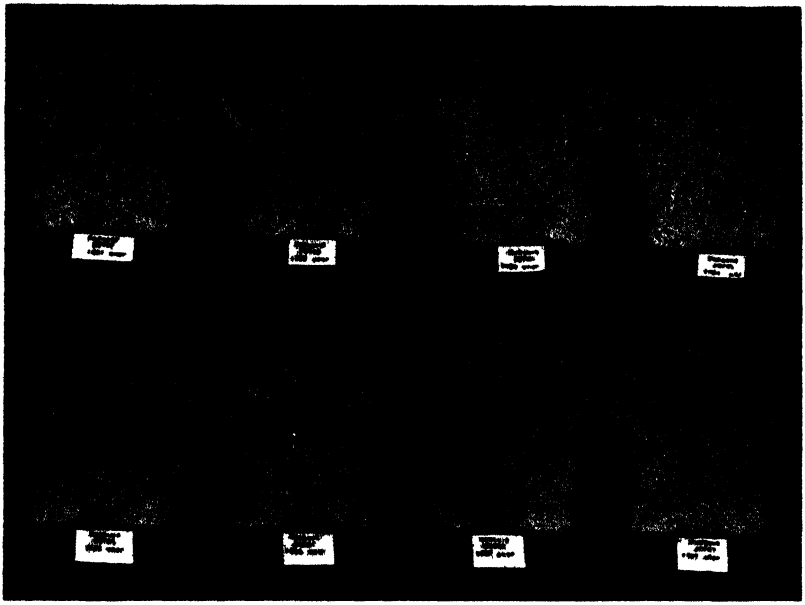

FIG. 1.—Loaves of bread baked in 1938 by the commercial-bromate procedure for Marquis grown in the various years 1921 to 1929.

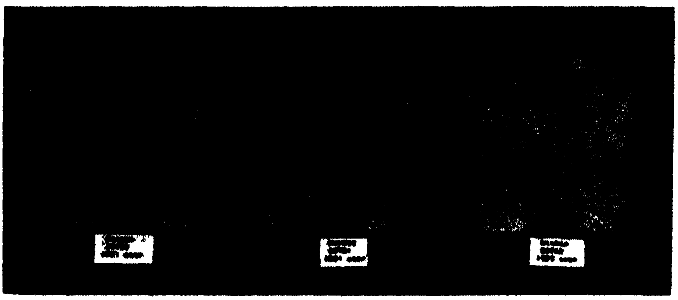

FIG. 2.—Loaves of bread baked in 1938 by the commerical-bromate procedure for Kanred from the crop years of 1921, 1924, and 1929.

All of the samples produced satisfactory bread. Strangely enough, the Marquis from the 1921 crop averaged highest in loaf volume and scored but slightly less in grain and texture than the 1929 Marquis, which was materially lower in loaf volume.

The 1921 Marquis was, it is true, relatively high in protein, 14.4%; nevertheless, it produced bread superior to that of the 1927 crop with

TABLE 1.—*Milling, baking, and related data for samples of Marquis and Kanred wheat varieties stored for various periods of time up to 17 years at the Colorado State College, Fort Collins, Colo.*

Item	Lab. No. 28742	Lab. No. 28743	Lab. No. 28744	Lab. No. 28745	Lab. No. 28746	Lab. No. 28747	Lab. No. 28748	Lab. No. 28749	Lab. No. 28750	Lab. No. 28751	Lab. No. 28752
Variety	Marquis	Marquis	Marquis	Marquis	Marquis	Marquis	Marquis	Marquis	Kanred	Kanred	Kanred
Year grown	1921	1922	1923	1924	1925	1926	1927	1929	1921	1924	1929
Analysis of wheat:											
U. S. Grade	3 DNS	2 DNS	4 DNS	3 NS	4 NS	3 DNS	2 DNS	1 HDNS	3 DHW	3 DHW	1 DHW
Test weight, lbs.*	59.8	61.9	60.5	62.9	57.8	63.6	61.2	63.3	60.1	63.7	62.9
Flour yield, %†	70.7	72.7	70.6	72.3	69.3	73.0	72.5	72.7	74.2	75.2	73.7
Protein, %‡	14.4	13.7	13.6	12.6	11.3	12.6	14.5	13.3	14.3	12.9	13.7
Ash, %‡	1.74	1.56	1.74	1.64	1.84	1.46	1.46	1.54	1.46	1.26	1.16
Moisture, %	10.7	11.0	10.5	10.4	10.5	10.6	10.5	10.6	10.6	10.5	10.6
Fat acidity§	47.7	42.8	47.4	34.8	43.2	32.4	31.3	26.2	37.5	31.8	26.7
Germination:											
6 months after harvest	98.0	97.5	93.0	93.5	97.5	95.5	98.5	97.0	95.0	94.0	93.0
In 1938	46.0	70.0	56.0	82.0	62.0	83.0	91.5	94.0	38.0	47.5	90.0
Analysis of flour:											
Protein, %‡	13.6	13.1	12.7	11.7	10.8	12.1	13.8	12.4	13.5	12.0	12.5
Ash, %‡	0.43	0.40	0.43	0.44	0.45	0.40	0.34	0.32	0.33	0.32	0.32
Gassing power, mm:											
1st hour	84	79	66	85	80	85	76	73	82	86	79
2d hour	129	89	68	107	121	110	64	72	122	94	81
3d hour	60	17	14	21	80	21	13	9	51	17	17
Total	273	185	148	213	281	216	153	154	255	197	177

Bread:											
Absorption (commercial), %	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.5	64.0	62.0
Loaf volume, cc:											
Commercial with 2% yeast	709	604	672	583	622	610	625	670	675	601	647
Commercial bromate with 2% yeast	684	604	650	577	577	595	645	647	737	644	691
Commercial with 3% yeast	661	604	616	557	619	583	598	604	685	604	664
Grain and texture:											
Commercial	85VG	70G	90VG	75G	80G	80G	85G	90VG	90VG	75G	90VG
Commercial bromate	90VG	75G	80G	75G	80G	85G	90VG	90VG	100VG	90VG	95VG
Commercial with 3% yeast	80VG	70G	85VG	70G	80G	75G	85G	85G	95VG	75G	85G
Color of crumb:											
Commercial with 2% yeast	95Cr	75Crgr	90Cr	85Cr	85Cr	90Cr	90Cr	100Cr	90Cr	85Cr	85Cr
Commercial bromate with 2% yeast	90Cr	80Cr	85Cr	80Cr	80Cr	85Cr	95Cr	95Cr	95Cr	90Cr	90Cr
Commercial with 3% yeast	85Cr	75Cr	90Cr	70Cr	75Cr	80Cr	80Cr	80Cr	95Cr	75Cr	80Cr
Single figure value:											
Commercial with 2% yeast	97.0	65.5	90.0	64.0	72.5	71.0	75.5	91.0	91.0	67.0	84.5
Commercial bromate with 2% yeast	93.0	67.5	78.5	61.5	63.0	69.0	85.5	85.5	106.5	85.0	95.5
Commercial with 3% yeast	84.5	65.5	77.5	55.0	71.5	63.5	69.5	70.5	95.0	67.0	82.5

*Dockage-free.
†Moisture-free.
‡13.5% moisture basis.
§Milligrams of KOH per 100-gram sample (dry matter basis)

practically the same protein content. Also the 1921 Kanred produced better bread than either the 1924 or the 1929 crops. Here, again, the protein content of the 1921 crop was relatively high.

Altogether, there is no indication in either the milling or baking data of any material deterioration in quality for bread of any of the samples.

SUMMARY

Milling and baking tests were made with eight samples of Marquis wheat and three samples of Kanred wheat stored at Fort Collins, Colorado, in a dry, unheated room for periods up to 17 years. There was a definite and fairly regular increase in fat acidity with storage, indicating a certain amount of progressive deterioration on storage. Satisfactory flour yields were obtained in all cases and unusual tempering was not required in any case. All lots made satisfactory bread, there being no indications of deterioration in baking quality in any of the samples. The best bread both from Marquis and Kanred was made from the 1921 crop, but the small difference as compared with later crops can probably be attributed to higher protein content. There was no apparent relation between deterioration in viability as shown by germination tests and baking quality.

THE FIXATION AND RELEASE OF APPLIED POTASH ON THREE COASTAL PLAIN SOILS[1]

J. M. BLUME AND E. R. PURVIS[2]

THE role of potassium in the chemical and physico-chemical phenomena of the soil has been the subject of exhaustive research; yet, one of the more practical aspects of the problem has not been entirely clarified. This concerns the fate of the potassium applied to soils in commercial fertilizers. The larger part of the element so added is probably utilized by the current crop; however, a considerable fraction remains in the soil in a water-soluble, replaceable, or fixed form. The controversial issues concern the fraction of the unutilized potassium which enters each of these three forms, and the ease with which it changes from one form to another. In areas where large quantities of commercial fertilizer are used, this unutilized potassium, plus the potassium returned to the soil in plant residues, represents, over a period of years, a considerable investment to the grower The practical considerations of the problem are apparent for it is important that the grower know what part of this investment is available for future use and what part is lost or becomes a frozen asset. This paper presents a study of the fate of potassium applied to three representative virgin soils of the vegetable-growing area of eastern Virginia.

EXPERIMENTAL PROCEDURE

An Elkton silt loam, a Portsmouth loamy fine sand, and a Sassafras sandy loam were chosen for the study. Various chemical data on the soils selected are presented in Table 1.

TABLE 1. *Characteristics of original soils*

Character	Portsmouth	Sassafras	Elkton
pH	4 1	4 6	5 30
pH after liming	6 1	6 0	7 2
Total nitrogen, %	0 43	0 183	0 095
Organic matter, %	21 6	4 5	1 5
Clay, %	5.0	17 0	9.0
Replaceable Ca, M.E./100 grams soil	2 06	1 45	1 5
Replaceable Mg, M E./100 grams soil	0 49	0 72	1 01
Replaceable K, M.E./100 grams soil	0.28	0 26	0 11
Exchange capacity, M.E./100 grams soil	27 0	11 1	5 2

The soils were collected from the virgin state, screened, all amendments added, thoroughly mixed, and placed in 2-gallon glazed earthenware urns. Fifty-six urns of each soil were divided into four series according to treatment and method of

[1]Contribution from the Virginia Truck Experiment Station, Norfolk, Va. Credit is given Dr. Jackson B. Hester, formerly of this Station, for assistance in outlining the problem and reading this manuscript, and to the American Potash Institute for supplying the funds which made this study possible. Received for publication August 5, 1939.

[2]Research Fellow and Soil Technologist, respectively.

study as follows: Series A, unlimed and unleached; series B, limed and unleached; series C, unlimed and leached; and series D, limed and leached.

Duplicates in each series received potassium treatments at the rate of 0, 50, 100, 200, 400, 800 and 1,600 pounds per acre of K_2O from commercial muriate of potash (62% K_2O). In addition, each urn received 2 grams of P_2O_5 and 2 grams of N from the sources Ammophos and urea. Hydrated magnesium lime was added to series B and D in amounts calculated to produce a soil reaction near pH 6.0. The reactions obtained are shown in Table 1. Because of the unexpected high silt and low colloid content, the Elkton soil, through error, was overlimed. The urns were placed in the greenhouse and the moisture content adjusted to one-half the water-holding capacity of the various soils. Constant moisture was maintained throughout the period of the study by weighing and adjusting twice weekly, with the exception of two weekly periods when watering was purposely omitted to permit the soils partly to dry.

Soil samples were drawn from each urn of series A and B at monthly intervals over a period of five months, and from series C and D after leaching at the ends of the first, third, and fifth months. To insure accurate sampling, 10 ¾-inch cores were drawn from each urn and thoroughly mixed. These samples were then subjected to analysis. Twelve and one-half grams of soil were leached with 250 mls. of water and the potassium determined in the leachate. Leaching with water was followed by leaching with 250 mls. of ½ N ammonium chloride solution adjusted to pH 7.0 with dilute ammonium hydroxide, and the replaceable potassium was determined. The fixed potassium was calculated from the amount added less the amount found in the water-soluble and replaceable states.

The urns of series C and D were subjected to monthly leachings with water, sufficient water being added to produce 2 liters of leachate at each leaching. These leachings were subjected to analysis for potassium by the sodium cobaltinitrite method, the method employed for all potassium determinations in this study.

RESULTS FROM UNLEACHED SERIES

The results from the study of series A and B are presented in Tables 2 and 3. It will be noted from Table 2, that in the case of the unlimed soils, only the Portsmouth fixed an appreciable amount of potassium. In this soil, the maximum fixation of potassium in all treatments occurred during the first two months. After the second month, part of this fixed potassium was apparently released, and at the end of the fifth month, the soils receiving the four higher treatments held in the fixed state approximately half as much potassium as was fixed at the end of the first month. There was considerable variation in the amount of potassium fixed within each treatment over the five months' period and there seems to be no consistency in this variation between treatments. It is believed that this inconsistency is significant for reasons which will be discussed later.

The unlimed Sassafras and Elkton soils fixed relatively little potassium at any time during the study, often showing negative fixation, i.e., release of potassium originally held in the fixed state.

Table 3 records the results from the study of the unleached, limed soils. As was expected, liming increased fixation in the Sassafras and Elkton soils. This was especially true in the case of the Elkton, for this soil in the limed condition showed a greater fixing power than

TABLE 2.—*Replaceable and fixed potassium on unlimed soils in M.E. of K per 100 grams of soil.*

	Days*	Pounds K_2O applied per acre						
		0	50	100	200	400	800	1,600
				Portsmouth				
M.E. K applied per 100 grams soil	—	0	0.086	0.173	0.345	0.690	1.380	2.760
Water-soluble plus replaceable K	30	0.310	0.320	0.430	0.510	0.695	1.040	1.810
	60	0.310	0.305	0.325	0.480	0.685	1.155	2.030
	90	0.280	0.280	0.370	0.555	0.905	1.315	2.390
	120	0.320	0.330	0.465	0.625	0.870	1.215	2.235
	150	0.320		0.410	0.615	0.855	1.385	2.285
Fixed K	30		0.076	0.053	0.145	0.305	0.650	1.260
	60		0.091	0.158	0.175	0.315	0.535	1.040
	90		0.086	0.083	0.070	0.065	0.345	0.650
	120		0.076	0.028	0.040	0.140	0.485	0.845
	150			0.083	0.050	0.155	0.315	0.795
				Sassafras				
M.E. K applied per 100 grams soil	—	0	0.063	0.125	0.250	0.500	1.000	2.000
Water-soluble plus replaceable K	30	0.230	0.285	0.350	0.445	0.805	1.050	2.065
	60	0.245	0.255	0.380	0.455	0.685	1.075	1.995
	90	0.225	0.265	0.425	0.425	0.715	1.185	2.085
	120	0.240	0.320	0.410	0.500	0.710	1.370	2.430
	150	0.230	0.285	0.345	0.450	0.710	1.215	2.675
Fixed K	30		0.008	0.005	0.035	−0.075	0.180	0.165
	60		0.053	−0.010	0.040	0.060	0.170	0.250
	90		0.023	−0.075	0.050	0.010	0.040	0.140
	120		−0.017	−0.045	−0.010	0.030	−0.130	−0.190
	150		0.008	0.010	0.030	0.020	0.015	−0.445
				Elkton				
M.E. K applied per 100 grams soil	—	0	0.052	0.104	0.208	0.415	0.830	1.660
Water-soluble plus replaceable K	30	0.095	0.140	0.220	0.295	0.605	0.940	1.875
	60	0.095	0.140	0.210	0.300	0.565	0.860	1.695
	90	0.095	0.155	0.220	0.400	0.560	1.030	1.900
	120	0.125	0.150	0.255	0.375	0.585	0.930	1.980
	150	0.080		0.150	0.300	0.540	0.830	1.880
Fixed K	30		0.007	−0.021	0.008	−0.095	−0.015	−0.120
	60		0.007	−0.011	0.003	−0.055	0.065	0.060
	90		−0.008	−0.021	−0.097	−0.050	−0.105	−0.145
	120		0.027	−0.026	−0.042	−0.045	0.025	−0.195
	150			0.034	−0.012	−0.045	0.080	−0.140

*Number days after application of potash at which sample was taken.

did the Sassafras, the reverse of what was found in the study of the unlimed soils.

Liming apparently had no effect upon the amount of potassium fixed by the Portsmouth soil although it did seem to affect the time of fixation, the greatest fixation occurring at the end of the fourth and

TABLE 3.—*Replaceable and fixed potassium on limed soils in M.E. of K per 100 grams of soil.*

	Days*	Pounds K_2O applied per acre						
		0	50	100	200	400	800	1,600
Portsmouth								
M.E. K applied per 100 grams soil	—	0	0.086	0.173	0.345	0.690	1.380	2.760
Water-soluble plus replaceable K	30	0.445		0.580	0.695	0.860	1.225	2.135
	60	0.405	0.440	0.525	0.615	0.925	1.255	2.175
	90	0.450	0.465	0.545	0.680	0.945	1.405	2.265
	120	0.440	0.455	0.530	0.680	0.875	1.385	2.085
	150	0.440	0.490	0.550	0.685	0.810	1.255	2.110
Fixed K	30			0.038	0.095	0.275	0.600	1.070
	60		0.051	0.053	0.135	0.170	0.530	0.990
	90		0.071	0.078	0.115	0.195	0.425	0.945
	120		0.071	0.083	0.105	0.255	0.435	1.115
	150		0.036	0.063	0.100	0.320	0.565	1.090
Sassafras								
M.E. K applied per 100 grams soil	—	0	0.063	0.125	0.250	0.500	1.000	2.000
Water-soluble plus replaceable K	30	0.310	0.390	0.450	0.550	0.830	1.220	2.260
	60	0.330	0.370	0.390	0.485	0.705	1.105	1.885
	90	0.260	0.300	0.400	0.535	0.755	1.215	2.130
	120	0.320	0.365	0.410	0.495	0.735	1.190	1.800
	150	0.265	0.300	0.400	0.470	0.725	1.250	2.300
Fixed K	30		-0.017	0.015	0.010	0.020	0.090	0.050
	60		0.023	0.065	0.095	0.125	0.225	0.445
	90		0.023	0.015	0.025	0.005	0.045	0.130
	120		0.018	0.035	0.075	0.085	0.130	0.520
	150		0.028	-0.010	0.045	0.040	0.015	0.035
Elkton								
M.E. K applied per 100 grams soil	—	0	0.052	0.104	0.208	0.415	0.830	1.660
Water-soluble plus replaceable K	30	0.140	0.160	0.185	0.240	0.450	0.745	1.540
	60	0.110	0.130	0.165	0.215	0.415	0.790	1.765
	90	0.100	0.170	0.200	0.310	0.420	0.830	1.780
	120	0.130	0.150	0.170	0.250	0.395	0.705	1.450
	150	0.105	0.135	0.170	0.240	0.400	0.755	1.425
Fixed K	30		0.032	0.059	0.108	0.105	0.225	0.260
	60		0.032	0.049	0.103	0.110	0.150	0.005
	90		-0.018	0.004	0.002	0.095	0.100	-0.020
	120		0.032	0.064	0.088	0.150	0.255	0.340
	150		0.022	0.039	0.073	0.120	0.180	0.340

*Number days after application of potash at which sample was taken.

fifth months instead of at the end of the first and second months as was the case with the unlimed soil.

The data presented in Tables 2 and 3 indicate that the properties of a soil which enable it to fix potassium in an unreplaceable state are dynamic and not constant. With chemical and physical factors con-

stant, this indicates that fixation is brought about by microbiological activity and is temporary in nature. It had been expected that a condition of equilibrium would be reached between the potassium existing in the water-soluble and replaceable conditions and the remainder which had become fixed. This condition of equilibrium was not obtained nor was there any evidence that it was being approached. There is a general correlation between the fixing power of the soils for potassium and their organic matter content and exchange capacity. This correlation holds in the case of the unlimed soils, the Portsmouth fixing the most potassium and the Elkton the least. However, when limed, the Elkton soil fixed practically as much potassium as did the Sassafras. This is probably explained by the difference in pH between the limed Sassafras and Elkton soils. As already mentioned, through error the Elkton was limed to pH 7.2 whereas the Sassafras and Portsmouth soils were limed to approximately pH 6.0. Although this prevents any direct comparison of the fixing capacity of the two soils, the difference in the amounts of potassium actually fixed are too small to be of any consequence.

In the above study, water-soluble potassium was included in the replaceable fraction as has been the common practice in studies of this type. To determine the importance of the water-soluble fractions, soil samples from the three higher treatments of series A and B were subjected to analysis for water-soluble potassium by the method already described. These data are presented in Table 4.

The separation of the water-soluble potassium from the replaceable fraction greatly clarifies the picture in the case of the Portsmouth and Elkton soils. With this separation, the replaceable fraction was found to be practically constant for each treatment throughout the entire period of the study and the amount held in the replaceable state was increased with each successive increment of potash applied. The entire variation in the amount of potassium fixed is reflected in the water-soluble fraction. Apparently the potassium is fixed from the water-soluble condition, the replaceable fraction of the element having no part in the phenomenon. One might assume that a very sensitive state of equilibrium exists in which the potassium fixed from the replaceable state is immediately replaced from the water-soluble fraction. The data presented are not contrary to such an assumption. The replaceable fraction did remain constant even though the water-soluble fraction varied over 100% in several instances. However, such would not be the case if the water-soluble fraction were evenly dispersed throughout the soil mass, for the replaceable fraction is increased as the amount of potassium applied is increased, as is shown in Table 4. To assume a constant replaceable fraction when the other two fractions vary widely is to ignore the conditions of the law of mass action. The percentage base saturation of a soil, with any ion capable of entering the exchange complex, must necessarily increase as the application of the ion in question is increased. To explain a constant replaceable fraction under conditions where the water-soluble fraction varies widely, as was found in this study, one must assume that the potassium released from the fixed state into a water-soluble form was not distributed throughout the soil mass and therefore had no

K determination	Days*	Portsmouth			Sassafras			Elkton		
		400† 0.690‡	800† 1.380‡	1,600† 2.760‡	400† 0.500‡	800† 1.000‡	1,600† 2.000‡	400† 0.415‡	800† 0.830‡	1,600† 1.660‡
Unlimed Soil										
Water-soluble K	30	0.210	0.365	0.745	0.245	0.500	1.060	0.385	0.625	1.225
	60	0.305	0.460	0.980	0.310	0.530	1.170	0.320	0.530	1.085
	90	0.425	0.630	1.305	0.395	0.680	1.545	0.310	0.645	1.355
	120	0.445	0.555	1.180	0.435	1.000	2.070	0.335	0.565	1.405
	150	0.430	0.715	1.245	0.400	0.900	2.285	0.365	0.560	1.310
Replaceable K	30	0.485	0.675	1.065	0.560	0.550	1.005	0.220	0.315	0.650
	60	0.380	0.695	1.050	0.375	0.545	0.825	0.245	0.330	0.610
	90	0.480	0.685	1.085	0.320	0.505	0.540	0.250	0.385	0.545
	120	0.425	0.660	1.055	0.275	0.370	0.360	0.250	0.365	0.575
	150	0.425	0.670	1.040	0.310	0.315	0.390	0.175	0.270	0.570
Fixed K	30	0.305	0.650	1.260	−0.075	0.180	0.165	−0.095	−0.015	−0.120
	60	0.315	0.535	1.040	0.060	0.160	0.250	−0.055	0.065	0.060
	90	0.065	0.345	0.650	0.010	0.040	0.140	−0.050	−0.105	−0.145
	120	0.140	0.485	0.845	0.030	−0.130	−0.190	−0.045	0.025	−0.195
	150	0.155	0.315	0.795	0.020	0.015	−0.445	−0.045	0.080	−0.140
Limed Soil										
Water-soluble K	30	0.320	0.500	1.090	0.240	0.370	1.370	0.200	0.450	1.070
	60	0.415	0.550	1.135	0.340	0.585	1.125	0.205	0.435	1.225
	90	0.375	0.715	1.315	0.360	0.685	1.380	0.175	0.450	1.240
	120	0.310	0.630	1.075	0.360	0.625	1.270	0.200	0.375	0.910
	150	0.345	0.635	1.155	0.360	0.740	1.915	0.175	0.425	0.925
Replaceable K	30	0.540	0.725	1.045	0.590	0.850	0.890	0.250	0.295	0.470
	60	0.510	0.705	1.040	0.365	0.520	0.760	0.210	0.355	0.540
	90	0.570	0.690	0.950	0.395	0.530	0.750	0.245	0.380	0.540
	120	0.565	0.755	1.010	0.375	0.565	0.530	0.195	0.330	0.540
	150	0.465	0.620	0.955	0.365	0.510	0.385	0.225	0.330	0.500
Fixed K	30	0.275	0.600	1.080	0.020	0.090	0.050	0.105	0.225	0.260
	60	0.170	0.530	0.990	0.125	0.225	0.445	0.120	0.150	0.005
	90	0.195	0.425	0.945	0.005	0.045	0.130	0.095	0.100	−0.020
	120	0.255	0.435	1.115	0.085	0.130	0.520	0.150	0.255	0.340
	150	0.320	0.565	1.090	0.040	0.015	−0.035	0.120	0.280	0.340

*Number of days after application of potash at which sample was taken.
†Pounds of K_2O applied per acre.
‡M. E. of K applied per 100 grams of soil.

opportunity to enter the exchange complex. If potassium fixation and release were the result of microbiological activity, the existence of potassium in a water-soluble but undispersed state could be accounted for. The dead bodies of microbes might well hold potassium against diffusion in a soil of limited moisture content, yet release this potassium under the treatment employed in the analysis for water-soluble potassium. This possibility of a microbiological factor will be discussed later.

The relationship between the water-soluble, replaceable, and fixed potassium for the 800-pound K_2O treatment on the unlimed Portsmouth soil is graphically illustrated in Fig. 1. The data from all treatments for both the unlimed and limed series of the Portsmouth and Elkton soils give similar curves.

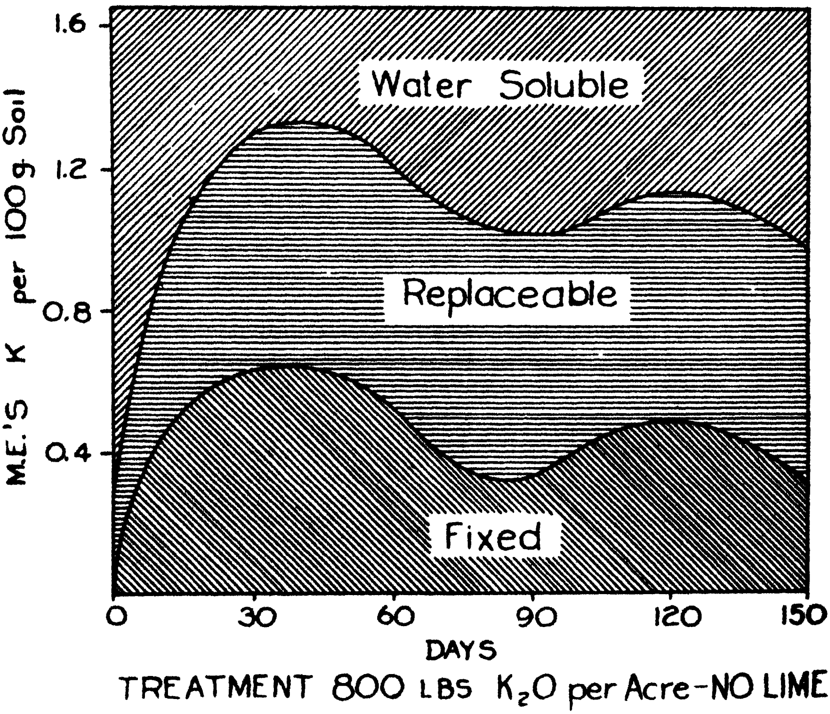

FIG. 1.—Fate of applied potash on Portsmouth soil.

For unexplained reasons the replaceable fraction of potassium did not remain constant in either the limed or unlimed series of the Sassafras soil but tended to decrease with time. The fixed fraction varied widely from month to month but also had a general tendency to decrease, both of these decreases being reflected by an increase in the water-soluble fraction. Apparently the exchange complex of this soil was appreciably altered during the study, possibly by rapid decomposition of the organic fraction.

In all three soils, the amount of potassium held in the replaceable state correlates well with their exchange capacities and organic matter contents.

RESULTS FROM LEACHED SERIES

In this series, the soils were leached monthly with sufficient water to produce 2 liters of leachate and the leachings analyzed for potassium. Soil samples were drawn at the end of the first, third, and fifth months after the urns had been leached. These samples were analyzed for water-soluble and replaceable potassium to determine what effect leaching had on this fraction. The results from this series are presented in Tables 5, 6, and 7.

TABLE 5.—*Percentage of applied potassium leached*

Pounds of K_2O applied per acre	Portsmouth		Sassafras		Elkton	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
50	27.9	12.8	25.4	0	25.0	3.8
100	26.0	12.7	37.6	10.4	37.5	14.4
200	26.1	11.3	42.0	16.4	36.5	19.2
400	30.0	14.2	34.2	19.2	33.5	19.0
800	26.4	16.9	40.1	30.8	49.4	22.9
1,600	31.9	20.0	41.7	47.0	56.1	36.8

TABLE 6.—*M.E. of replaceable K + water-soluble K per 100 grams of soil, samples taken after monthly leachings*

Pounds of K_2O applied per acre	Portsmouth			Sassafras			Elkton		
	30 days	90 days	150 days	30 days	90 days	150 days	30 days	90 days	150 days
				Unlimed Soil					
None	0.330	0.090	0.110	0.190	0.180	0.135	0.065	0.035	0.060
50	0.315	0.090	0.190	0.190	0.205	0.195	0.100	0.080	0.090
100	0.315	0.305	0.280	0.250	0.240	0.220	0.140	0.115	0.120
200	0.490	0.390	0.360	0.380	0.385	0.290	0.190	0.165	0.210
400	0.645	0.535	0.530	0.445	0.535	0.390	0.330	0.275	0.270
800	0.935	0.860	0.845	0.805	0.715	0.650	0.595	0.350	0.405
1,600	1.370	1.240	1.125	1.340	1.045	1.015	0.895	0.610	0.640
				Limed Soil					
None	0.345	0.325	0.365	0.225	0.225	0.240	0.145	0.055	0.080
50	0.385	0.350	0.390	0.275	0.235	0.235	0.150	0.080	0.145
100	0.430	0.430	0.480	0.335	0.275	0.295	0.175	0.135	0.160
200	0.540	0.550	0.555	0.400	0.360	0.370	0.230	0.180	0.200
400	0.895	0.770	0.740	0.485	0.505	0.520	0.355	0.270	0.325
800	0.995	1.145	1.060	0.725	0.750	0.690	0.630	0.480	0.560
1,600	1.425	1.665	1.445	1.175	1.155	1.130	1.065	0.835	0.795

It will be noted from Table 5 that from a third to a half of the potassium applied on the unlimed soils was removed by leaching. The percentage figures are strikingly consistent for all treatments in the case of the Portsmouth soil. This indicates that similar percentages of the potash applied in all treatments became water-soluble at one time or another during the five months' period and therefore that the potash was removed on a percentage basis. To a lesser extent, the

same relationship holds with the unlimed Sassafras and Elkton soils. Here, however, there is a tendency for the percentage removal to increase with the increase in amount of potassium applied. Since these soils fixed considerably less potassium than did the Portsmouth, more of the element remained in water solution and, therefore, a higher percentage was leached out.

The limed soils lost less potassium than did the unlimed ones. It is believed that this was due to the granulation of the soil by the lime. A floculated soil would naturally be less thoroughly leached than one in which the organic matter and clay were in a defloculated condition. Evidence of the correctness of this theory is presented in Table 6 where it is seen that the limed soils retained considerably more potassium in the water-soluble and replaceable forms, after leaching, than did the unlimed soils. This was especially true at the end of the five months' period.

Since tap water had been used in leaching the above soils, the experiment was repeated with the Portsmouth soil using rain water for leaching in order to eliminate the possibility of potassium replacement by soluble ions in the tap water The results obtained were in close agreement with those of Table 5 and for this reason are not included here

Table 6 presents the results for water-soluble and replaceable potassium obtained by analysis of the soils after the first, third, and fifth leaching. With the exception of the two higher treatments of the unlimed Elkton soil, all three soils in all treatments retained more potassium in the water-soluble and replaceable forms at the end of the fifth leaching than was lost in all five leachings, the limed soils retaining a higher percentage as already mentioned. This indicates the importance of soil structure in the retention of soluble ions against leaching and also suggests that the actual loss of potassium from the soil through leaching is much less than would be expected, although it remains in the soil in a water-soluble form.

TABLE 7.—*M.E. of K fixed per 100 grams of soil at end of a five months' period.**

Pounds of K_2O applied per acre	Portsmouth		Sassafras		Elkton	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
50	0.018	0.050	-0.013	0.069	0.009	-0.015
100	-0.012	0.036	0.007	0.057	0.004	0.009
200	0.005	0.116	-0.010	0.079	-0.018	0.048
400	0.043	0.217	0.074	0.124	0.066	0.091
800	0.280	0.451	0.084	0.242	0.075	0.160
1,600	0.863	1.124	0.286	0.295	0.149	0.333
M.E. K leached or available per 100 grams soil of O treatment	0.174	0.431	0.192	0.278	0.084	0.100

*K applied plus [K leached, H_2O-soluble and replaceable of O treatment] less [K leached, H_2O-soluble and replaceable of respective treatments].

The amount of the applied potassium which was not accounted for in the leachings or in the water-soluble and replaceable fractions at

the end of the five months' period must be considered as fixed by the soil. The data for this fraction are presented in Table 7. To arrive at the correct values, the amount of K_2O leached from the "no potash" treatment plus that held in the water-soluble and replaceable states in this treatment at the end of the study, were subtracted from the results of all other treatments. Without this correction, all treatments, with the exception of the two higher ones, would show negative fixation (the release of K_2O originally held in fixed state). Even with the correction, negative fixation occurs in a number of instances and fixation is generally low for all of the lower treatments. It has been shown (Fig. 1) that the fixed and water-soluble fractions vary inversely with one another, while the replaceable fraction remains fairly constant. This being the case, the periodic removal of the water-soluble fraction by leaching would progressively lower the fixed fraction until it disappeared completely. The replaceable fraction would also be lowered as the water-soluble portion was removed. The data of Table 7 support this hypothesis and indicate that all of the applied K_2O would be recovered in the water-soluble form in a comparatively short time.

DISCUSSION

It is generally agreed that under certain conditions soils are able to fix potassium in a non-replaceable form. Volk (8)[3] obtained approximately 100% fixation of applied potassium by alternately wetting and drying the soil, but found that no fixation occurred when the moisture content was maintained near the optimum for plant growth. Hoagland and Martin (4) state that, in some soils, all of the applied potassium may enter the replaceable state, while in other soils considerable amounts of the potassium may be fixed.

Perhaps the most significant fact established in the present study is that the fixation of potassium by a soil is a highly reversible phenomenon. Over a five months' period, the amount of applied potassium held in the fixed state in soils maintained at constant moisture and sampled monthly, varied by as much as 100%. Potassium enters the fixed state, is released, and becomes fixed again in a comparatively short time. This is in agreement with the findings of Abel and Magistad (1), Bray and De Turk (2), and many other investigators. However, the data obtained do not support the theory that potassium fixation and release follow the line of an equilibrium reaction. As previously stated, the variation in the amount of potassium fixed over a five months' period was reflected in an inverse variation in the amount of potassium in the water-soluble form, while the amount of the element held in the replaceable state remained constant after the first month.

Since fixation was greatest in the Portsmouth soil which contained the highest percentage of organic matter, and since the variation in the amount of potassium fixed at various samplings was so great, the possibility of a microbiological activity factor is suggested. It is admitted that the data offer no concrete proof of such a factor other than by inference. However, as shown in Fig. 1, the curve for fixed

[3]Figures in parenthesis refer to "Literature Cited", p. 868.

potassium is similar to growth curves of the soil microflora over a period of time. The direct variation between water-soluble and fixed potassium may also be interpreted as evidence of a microbiological factor, since the soil fungi and bacteria would naturally utilize the water-soluble potassium.

Many investigators attribute to potassium an important part in the base exchange reactions of the soil. Merkle (7) found that long-continued use of muriate of potash on a soil increased the replaceable potassium content and reduced the replaceable calcium content. Magistad (6) states that the response of crops in the field to potash is very definitely correlated with the amount of replaceable potassium present. Lamb (5) came to the opposite conclusion, while Gedroiz (3) questioned the actual existence of replaceable potassium in the soil. The data obtained in this study indicate that a considerable part of the applied potash enters into a replaceable state in the soil and that this replaceable potassium will be hydrolized when the water-soluble fraction is reduced by leaching, as is shown in Table 6. The consistency of the replaceable fractions in the unleached series is therefore an unnatural phenomenon due to the constant moisture content maintained. The moisture present was not sufficient to distribute the potassium released from the fixed state, or to hydrolyze the replaceable potassium as the water-soluble fraction was depleted by fixation. It follows from this reasoning that all of the applied potash would become water soluble readily as the existing water-soluble fraction is reduced through leaching or crop removal. This is in accord with the results shown in Table 7.

From a practical standpoint, the results of this study indicate that there is practically no loss of applied potassium on the Coastal Plain soils of Virginia through chemical fixation. Such fixation as does occur is more beneficial than harmful in that it tends to retain temporarily the element in an unleachable state but eventually releases it into a water-soluble form. During the growing period of the average crop it is likely that practically all of the potassium applied in commercial fertilizer is available to that crop at one time or another. Likewise, practically all of the applied potassium is subject to loss by leaching during the growth of the crop. Work now in progress, however, indicates that actual loss by leaching may not be very great since the potassium leached from the surface zone by heavy rains may be returned by evaporative forces during dry weather. This suggests the feasibility of light side applications of potash after heavy rains to tide the plants over a temporary deficiency of this element.

SUMMARY

A study is reported of the fate of potassium applied at the rates of 50, 100, 200, 400, 800, and 1,600 pounds of K_2O per acre to an Elkton silt loam, a Portsmouth loamy fine sand, and a Sassafras sandy loam. Analyses for water-soluble, replaceable, and fixed potassium were made at monthly intervals over a five months' period on limed, unlimed, leached, and unleached, soils kept under greenhouse conditions.

The amount of potassium fixed in all treatments varied greatly from month to month indicating that the properties of a soil which affect fixation are dynamic in nature. The possibility of microbiological fixation is suggested and supported by evidence of an inverse relationship between water-soluble and fixed potassium.

Under controlled conditions, the amount of potassium held in the replaceable state remained constant over the five months' period in the Portsmouth and Elkton soils, while the fixed fraction varied greatly, the variation being reflected in the water-soluble fraction.

Monthly removal of the water-soluble potassium by leaching greatly reduced the replaceable and fixed fractions of potassium in all soils.

LITERATURE CITED

1. ABEL, F. A. E., and MAGISTAD, O. C. Conversion of soil potash from the non-replaceable form. Jour. Amer. Soc. Agron. 27:437–445. 1935.
2. BRAY, R. H., and DE TURK, E. E. The release of potassium from non-replaceable forms in Illinois soils. Soil Sci. Soc. Amer. Proc., 3:101–106. 1939.
3. GEDROIZ, K. K. Exchangeable cations of the soil and the plant: 1. Relation of plant to certain cations fully saturating the soil exchange capacity. Soil Sci., 32:51–63. 1931.
4. HOAGLAND, D. R., and MARTIN, J. C. Absorption of potassium by plants in relation to replaceable, non-replaceable, and soil solution potassium. Soil Sci., 36:1–33. 1933.
5. LAMB, JOHN JR. The availability of soil potassium. Soil Sci., 40:365–381. 1935.
6. MAGISTAD, O. C. The relation between replaceable potassium and field response to potash in Hawaiian soils. Soil Sci., 31:99–108. 1934.
7. MERKLE, F. G. Base exchange studies on the Pennsylvania Jordan field plats. Soil Sci., 38:37–64. 1934.
8. VOLK, N. J. The fixation of potash in difficultly available form in soils. Soil Sci., 37:267–287. 1934.

CHEMICAL COMPOSITION OF DIPLOID AND TETRAPLOID *LOLIUM PERENNE* L.[1]

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SOME chemical differences have been recorded between diploid and tetraploid strains of the same species. According to Sansome and Zilva,[3] tetraploid strains of the tomato were higher than diploid in vitamin C. Randolph and Hand[4] found that tetraploid strains of yellow corn were higher than diploids in carotenoids. A comparison is made here of the composition of diploid with colchicine-induced tetraploid tissue of *Lolium perenne*.

Following treatment of seeds of *Lolium perenne* with colchicine, plants were obtained which were chimeras of diploid and tetraploid tissue. By vegetative reproduction diploid and tetraploid clones have been established from a number of these plants. There is no evidence that colchicine produced in this material any other effects than chromosomal reduplication. In the absence of any other effects the diploid and tetraploid clones from each plant should differ genetically in a quantitative manner only, that is by the tetraploid having double the number of chromosomes and, consequently, twice as many alleles of each gene. Thus, this material affords an opportunity of measuring the effects of chromosomal and genic reduplication on chemical composition without the complication of gene differences.

Chemical analyses have been made of the diploid and tetraploid clones from each of five original seedlings. Cuttings were grown in 10 rows in the greenhouse bed. Each of the five original seedlings were represented by two rows distributed at random and each row contained eight individual cuttings consisting of three to five diploid and three to five tetraploid individuals. At the end of the two months the plants were still in a vegetative condition. They were then harvested (February 3, 1939) and the tops of all diploid plants in one row were composited and the tops of all tetraploids in the same row were also composited in another sample. (The samples averaged 50 grams of green weight.) Thus, from the 10 rows 10 pairs of samples were obtained; each pair consisted of one diploid and one tetraploid sample, both from the same original seedling and both grown in the same row.

The samples were preserved and extracted with hot alcohol. Analyses were made for dry matter, for reducing sugars and sucrose according to the bicarbonate method of Phillips,[5] and for crude fiber, total alcohol-soluble nitrogen to include nitrates, and insoluble nitro-

[1]Contribution of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the northeastern states. Received for publication August 11, 1939.

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[3]Biochem. Jour., 27:1935–1941. 1933.

[4]Science, 87:442–443. 1938.

[5]Jour. Biol. Chem., 95:735–742. 1932.

TABLE 1.—*Percentages of dry matter, crude fiber, sugars, and nitrogen in diploid and tetraploid plants of Lolium perenne.*

Plant	Row	Dry matter in percentage of fresh weight		Total alcohol-soluble matter in percentage of dry weight		Crude fiber in percentage of dry weight		Reducing sugars in percentage of dry weight		Sucrose in percentage of dry weight		Total sugars as invert in percentage of dry weight		Insoluble nitrogen in percentage of dry weight		Alcohol-soluble nitrogen in percentage of dry weight		Total nitrogen in percentage of dry weight	
		Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid	Diploid	Tetraploid
C 116	1	15.8	13.7	29.8	31.2	21.10	21.83	0.38	0.55	1.71	1.92	2.18	2.57	3.73	3.72	1.25	1.33	4.98	5.05
	10	16.5	16.8	31.5	31.9	20.20	20.14	0.34	0.31	2.56	3.28	3.02	3.76	3.69	3.72	1.28	1.03	4.97	4.75
C 58	2	17.0	15.8	30.8	31.5	20.88	21.35	0.47	1.01	2.54	2.50	3.14	3.66	3.58	3.57	1.13	1.04	4.71	4.61
	7	18.4	20.0	32.9	34.2	19.86	18.92	0.85	1.09	4.86	5.49	5.96	6.86	3.33	3.38	1.04	0.89	4.37	4.27
C 217	3	13.5	13.4	32.2	32.3	22.12	22.24	1.61	1.81	2.44	3.13	4.17	5.11	3.24	3.19	1.28	1.20	4.52	4.39
	9	13.8	14.4	32.3	32.4	21.44	21.38	0.93	1.52	1.73	2.28	2.74	3.92	3.52	3.25	1.46	1.34	4.98	4.59
C 101	4	15.2	14.9	30.8	32.4	21.02	20.32	0.60	0.64	2.80	3.24	3.55	4.05	3.53	3.46	—	—	—	—
	6	15.4	16.1	32.3	31.6	20.15	19.76	0.43	0.67	3.63	4.17	4.25	5.07	3.59	3.56	1.34	1.27	4.93	4.83
C 177	5	15.8	15.8	33.4	33.8	19.78	19.83	1.95	2.47	4.11	4.75	6.28	7.47	3.46	3.41	—	—	—	—
	8	16.7	16.9	33.4	36.0	19.61	19.13	1.80	1.61	4.48	4.13	6.51	5.96	3.49	3.40	1.15	1.29	4.64	4.69
Mean		15.81	15.78	31.94	32.73	20.616	20.490	0.936	1.168	3.086	3.489	4.180	4.843	3.516	3.466	1.241	1.174	4.762	4.647
Significance		t = 0.93*		t = 2.64*		t = 0.79*		t = 2.86*		t = 3.66*		t = 4.14*		t = 1.79*		t = 1.50†		t = 2.07†	

*With 9 degrees of freedom values of t for P of 0.05 and P of 0.01 are 2.262 and 3.250, respectively

†With 7 degrees of freedom the value of t for P of 0.05 is 2.365.

gen. The limited amount of material prevented a more complete analysis.

The results were summarized in Table 1. In the statistical analysis, *t* was calculated by the pairing method and values of *t* for P of 0.05 and 0.01 were taken from Fisher's[6] table of *t*.

The tetraploid plants were higher than the diploid in reducing sugars, sucrose, total sugars, and in the proportion of dry matter that was soluble in 80% alcohol. The *t* for comparison of reducing sugars and soluble dry matter exceeded the value of *t* for P of 0.05; for sucrose and total sugars *t* exceeded the value of *t* for P of 0.01 Therefore the differences can probably be considered statistically significant. The tetraploids in this study were, in general, lower in both soluble and insoluble nitrogen, but the differences were of such slight magnitude as to have no statistical significance. No consistencies were found in total dry matter and crude fiber.

It may be concluded that under the conditions of the experiments and with the material used, chromosomal and genic reduplication causes an increase in the sugar content of *Lolium perenne*.

[6]Statistical Methods for Research Workers. Edinburgh: Oliver & Boyd. Ed. 6. 1936.

LOSS RESULTING FROM PULLING LEAVES WITH THE TASSELS IN DETASSELING CORN[1]

G. H. DUNGAN AND C. M. WOODWORTH[2]

SPEEDING up detasseling in the commercial production of hybrid seed corn may sometimes result in the removal of a few of the upper leaves along with the tassel. In order to get some measure of reduction in yield of grain following careless detasseling, an experiment was conducted in which the tassel alone was removed and also in which one to four of the upper leaves were removed along with the tassel.

The corn used was U. S. Hybrid 35 (R4×Hy) (WF9×38-11). A plat consisted of three hills each containing from two to three plants. Each treatment was represented by 14 systematically replicated plats, making a total of 42 hills. Individual plat yields were taken and all data presented are averages of the 14 plats of each treatment.

Detasseling was done just as the tassel appeared above the whorl formed by the upper blades. The tassel only, the tassel with one leaf, and the tassel with two leaves were jerked out while grasping the part to be removed in one hand and holding the plant below the point of the desired break with the other. Removal of the tassel with three leaves and the tassel with four leaves was done by cutting off the stalk with a knife at the proper place. The amount of plant tissue removed in the respective treatments is shown in Fig. 1.

RESULTS

A summary of the results obtained from the removal of no to four leaves along with the tassels is shown in Table 1.

TABLE 1.—*Influence of removing tassels with different numbers of leaves on yield of corn and weight of kernels, Urbana, Ill., 1938.*

Treatment No.	Part of plant removed when tassel emerged	Number of plants	Average weight of 500 kernels, grams	Average yield of shelled corn per plant	
				Pounds	%
1	Tassel only	106	139.6	0.724±0.0182*	100.0
2	Nothing	113	137.1	0.710±0.0189	98.6
3	Tassel and one leaf	112	130.5	0.660±0.0221	91.7
4	Tassel and two leaves	110	128.9	0.610±0.0216	84.7
5	Tassel and three leaves	107	128.8	0.590±0.0144	81.9
6	Tassel and four leaves	117	124.1	0.510±0.0149	70.8

*Standard error

Removal of tassel and four leaves reduced the yield of grain almost 30% below that of careful detasseling. When one leaf was removed with the tassel the yield was reduced a little more than 8%. Two leaves pulled with the tassel caused a 15% lowering of yield and three leaves removed with the tassel lowered the yield over 18%.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication Aug. 11, 1939.
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FIG. 1.—A typical set of corn tops illustrating, from left to right, the tassel alone, tassel with one leaf, tassel with two leaves, tassel with three leaves, and tassel with four leaves.

The data were studied statistically to determine the probability that the differences between the means of the various treatments were significant. The standard error of the mean of the results for any one treatment was calculated and is recorded in Table 1. Then for a comparison of any two treatments, the difference between the two means was determined and divided by the standard error of the difference. If the quotient thus obtained was as high as 2 or higher, it was considered that the difference between the means being compared was the result of the treatment and not simply due to errors of random sampling. The treatment comparisons are given in Table 2.

TABLE 2.—*Statistical comparisons between treatments.*

Treatments	Difference±standard deviation of the difference	D/S.D. difference
1 and 2	0.014±0.0262	0.5343
1 and 3	0.064±0.0286	2.2377
1 and 4	0.114±0.0282	4.0425
1 and 5	0.134±0.0232	5.7758
1 and 6	0.214±0.0235	9.1063
2 and 3	0.050±0.0290	1.7241
2 and 4	0.100±0.0287	3.4843
2 and 5	0.120±0.0237	5.0632
2 and 6	0.200±0.0240	8.3333
3 and 4	0.050±0.0309	1.6148
3 and 5	0.070±0.0263	2.6615
3 and 6	0.150±0.0266	5.6391
4 and 5	0.020±0.0259	0.7722
4 and 6	0.100±0.0262	3.8167
5 and 6	0.080±0.0207	3.8647

As seen in Table 2, only 4 of the 13 possible comparisons gave a quotient (D/S.D. diff.) of less than 2. These were treatments 1 and 2, 2 and 3, 3 and 4, and 4 and 5. Differences in all other comparisons were statistically significant.

Statistically, therefore, there was no difference between plants not detasseled at all and those from which only the tassel or the tassel and one leaf were removed. Also, there was no difference between the removal of one or two blades with the tassel nor between the removal of two or three blades with the tassel.

The falling off of yield of grain as a consequence of leaves removed from the corn plant is in line with the results of investigations by Hume and Franzke (3),[3] Eldredge (2), and Dungan (1), all of whom found that the severance of corn blades at the time the plants were in the early phase of reproduction caused a more marked reduction of grain yield than the removal of the same number of blades earlier or later in the development of the crop. When leaves are taken off before the tassel appears new leaves will unfold as the plant develops. If the blades are not removed until after the ear has developed to some degree, the plant has had the advantage of some photosynthetic

[3]Figures in parenthesis refer to "Literature Cited", p. 875.

activity of the leaves and therefore produces more grain than if the leaves had been taken off earlier.

Plants from which the tassel was carefully removed produced 1.4% greater yield than non-detasseled plants. Leonard and Kiesselbach (5) obtained an increase in yield amounting to 1.5% as a result of detasseling. These workers also review the publications of others, covering 11 trials, 6 of which showed an increase in yield resulting from detasseling. In three of these, detasseling resulted in a reduction of yield and in one no difference in grain yield occurred. Tests in France (5) revealed that the sugar content of the stalks of detasseled plants was higher than that of non-detasseled stalks.

Isidoro (4), working with flint corn in the Philippine Islands, found as a result of comprehensive tests using ear-to-row planting and mass seed plantings at two different planting dates that detasseling resulted in an increase in grain yield of 10%, a difference which was statistically significant.

That pulling out the tassel with and without leaves had an influence upon grain development is further borne out by the data on weight of 500 kernels (Table 1). The average kernel weights were progressively less, almost exactly paralleling the yield reductions following the various detasseling treatments.

SUMMARY

In the commercial production of hybrid corn, tassels are usually jerked out hurriedly and frequently some of the upper leaves are pulled out with the tassel. An experiment was conducted at the Illinois Agricultural Experiment Station in 1938 to obtain information concerning the loss in grain yield resulting from careless detasseling. It was found that:

1. Pulling one leaf with the tassel in detasseling corn reduced the yield of grain 8.3%; pulling two leaves lowered the yield 15.3%; pulling three leaves lowered the yield 18.1%; and pulling four leaves reduced the yield 29.2%.
2. Detasseling without removing any leaves resulted in a yield increase of 1.4% over that of non-detasseled plants.
3. The weight of 500 kernels was materially reduced by pulling leaves with the tassel.
4. These results emphasize the economic importance of detasseling the ear parent plants in breeding plats carefully so that the minimum amount of injury be inflicted.

LITERATURE CITED

1. Dungan, G. H. Losses to the corn crop caused by leaf injury. Plant Phys., 9:749–766. 1934.
2. Eldredge, J. C. Effect of injury in imitation of hail damage on the development of the corn plant. Iowa Agr. Exp. Sta. Res. Bul. 185:1–61. 1935.
3. Hume, A. N., and Franzke, Clifford. The effect of certain injuries to leaves of corn plants upon weights of grain produced. Jour. Amer. Soc. Agron., 21:1156–1164. 1929.
4. Isidoro, F. R. Study of the immediate effects of detasseling upon the yield of Calauan Yellow Flint corn planted ear-to-row, and by the ordinary method. Philippine Agr., 23:225–237. 1934.
5. Leonard, Warren H., and Kiesselbach, T. A. The effect of the removal of tassels on the yield of corn. Jour. Amer. Soc. Agron., 24:514–516. 1932.

THE EFFECT OF MATURITY AT TIME OF HARVEST ON CERTAIN RESPONSES OF SEED OF CRESTED WHEATGRASS, *AGROPYRON CRISTATUM* (L.) GAERTN.[1]

ELIZABETH MCKAY HERMANN AND WILFORD HERMANN[2]

THE increased use of *Agropyron cristatum* (L.) Gaertn. as a forage crop and for soil erosion control has created a demand for information pertinent to management methods. As many days may elapse between the first and final dates of ripening among plant populations, the grower is confronted with the problem of harvesting at a time when the maximum production of mature seed will be obtained. Premature harvests may result in seed which germinates poorly or contains little reserve food, which delayed harvests may permit shattering of ripened seed and a consequent reduction in yields.

It has been shown by Kiesselbach (5)[3] that seed size is not associated with plant yield in corn, but Kiesselbach and Helm (6) have reported that seed size materially influences plant yield in wheat. Salisbury (12) has discussed the relation between size, strength, and maturity of propagules and ability of the plant to establish itself under conditions of competition. Plants from small, weak, immature propagules are placed at a distinct disadvantage when competing for establishment with plants grown from larger propagules. It seems possible that immature, small seed of *Agropyron cristatum* may have a lessened chance of establishment in competition with the same or other species.

Studies by Hay (2, 3, 4) of the germination of crested wheatgrass have indicated that mature, freshly-harvested seed germinates more readily when held at a temperature below 20° C for part of the germination period, but that dry storage of the seed decreases the need for low-temperature treatment during the germination period.

Seedling emergence of crested wheatgrass when seeded at various depths has been reported by Kirk, Stevenson, and Clarke (7), Love and Hanson (10), and Murphy and Arny (11) whose conclusions were similar. Germination was good in surface plantings if satisfactory moisture conditions were maintained. Percentages of emergence decreased with an increase in depth of planting with the optimum depth being less than 1 inch and preferably ½ inch. Emergence (10) and non-emergence (7) of seedlings from planting depths of greater than 2 inches were both reported, but this variation in results might have been due to differences in soil types (11). The investigations reviewed were apparently made with well-ripened seed.

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[3]Figures in parenthesis refer to "Literature Cited", p. 884.

In order to obtain information which might be useful in determining a favorable cutting date, seed was harvested at several stages of maturity and investigations were made of the quality of the seed obtained. Experiments were planned to determine the relation of maturity of the seed at harvest to the increase and maximum germination with storage, to the time required to complete germination, to the response to prechilling of the seed before germination, to the effect of different temperatures upon germination, and to the apparent amount of reserve food in the endosperm.

PROCEDURE

Spikes of a 3-year-old stand of standard *Agropyron cristatum* grown in 16-foot single rows spaced 2 feet apart in the Washington Agricultural Experiment Station grass nursery were tagged with the date of anther exsertion. Beginning nine days later, when seed was in the premilk stage, 200 spikes were harvested every three days until the seed was in the soft dough stage, after which date harvests were made at six-day intervals until about 50% of the seed had shattered. Harvesting dates extended from the end of June to the first week of August, 1937. Seed was stored in paper bags at room temperature until tested. Germination tests were made between paper towels in a standard germinating chamber. Temperature of the germinating chamber was 20° C ±2° C, except when otherwise specified.

Four lots of 100 seeds each were used for each test, and percentages of germination were determined by averaging all the lots that fell within the limits of tolerance as outlined by Leggatt (8). Standard errors of the different tests were computed by the machine method as recommended for application to seed testing by Collins (1). Individual errors rather than a generalized error were used because average percentages were occasionally based on fewer than four lots of seed. The standard errors for other phases of the study were determined in accordance with small population formulae of Love (9).

RESULTS AND DISCUSSION

EFFECT OF STORAGE

Germination tests were begun immediately after harvest and every seven days for 11 weeks. After 11 weeks the period between tests was lengthened. Germination was determined for seed of some of the harvests after approximately 525 days of storage (Table 1). As no germination occurred in the seed of the premilk stage through five weeks after harvest, tests were discontinued. None were made of the early milk seed after the eleventh week as all tests to that time were low and no increase had occurred for several weeks. Seed of other degrees of maturity was tested until the supply was exhausted.

Percentages of germination in all tests made immediately after harvest were noticeably low as compared with those of subsequent tests. This was especially marked preceding and through the development of soft dough, where initial tests showed almost no germination. Seed of all stages of maturity increased in percentages of germination after storage, but the length of the storage period required to reach maximum germination was proportionately less as the maturity of the seed increased. Ripe seed attained maximum

TABLE 1.—*Relation of maturity at time of harvest to the increase of germination after storage and the maximum germination of seed of Agropyron cristatum.*

Stage of maturity at harvest	Days after anther exsertion	Number of days of storage between harvesting and testing*																	
		0 %	7 %	14 %	21 %	28 %	35 %	42 %	49 %	56 %	63 %	70 %	77 %	85† %	110† %	165† %	225† %	280† %	525† %
Premilk . . .	9	0	0	0	0	0	0	—	—	—	—	—	—	—	—	—	—	—	—
Early milk.	12	0	0	1	1	3±1	4±1	5±1	15±2	12±1	11±4	12±1	8±2	—	—	—	—	—	—
Milk.	15	0	1	2±1	9±1	24±2	28±2	22±3	26±1	21±1	23±2	33±4	42±2	45±2	64±3	60±2	—	—	—
Late milk. .	18	1	1	11±3	2±1	64±3	63±2	46±2	65±1	73±3	66±2	67±3	58±5	67±2	73±1	65±1	70±2	62±1	64±2
Early dough	21	2±1	38±3	84±3	73±2	64±2	85±2	85±1	84±1	81±3	75±2	87±2	89±1	90±1	88±2	93±1	92±2	84±1	—
Soft dough.	24	8±1	59±2	74±3	82±4	86±2	88±1	86±1	86±2	87±1	83±4	83±1	89±2	76±3	93±1	87±3	86±2	89±1	88±1
Hard dough	30	53±2	63±1	83±2	83±2	87±2	88±1	92±1	90±1	—	94±1	90±2	87±1	93	94±1	95±1	96±1	93±1	—
Ripe	36	77±2	78±3	89±1	83±2	85±2	91±2	91±1	92±2	94±1	92±2	95±1	95±1	94±2	95±1	95±1	—	—	—
Slightly shattered	42	73±3	87±1	82±2	78±2	90±1	89±1	84±3	91±2	91±2	91±1	92±1	96±1	93±3	95±1	94±2	95±1	96±1	—
Shattered 50%	48	74±3	78±1	94±1	89±1	90±2	92±1	91±1	95±1	94±1	95±1	93±1	92±2	94±1	95±1	97±1	95±2	96±2	94±1

*Tests were made at 20° C between paper towels, using four lots of 100 seeds each.
†Approximate.

percentages of germination after two weeks of dry storage following harvest.

Maximum percentages of germination increased with greater maturity of the seed through the late milk stage, beyond which differences in stored seed were not significant. Maximum germination up to and including the late milk stage was 70 to 75%, while all seed from later harvests reached maximums of more than 90%.

SPEED OF GERMINATION

Records were made of the number of days required to complete germination. The time required for completion of tests, summarized in Table 1, is shown graphically in Fig. 1 for seed of five different

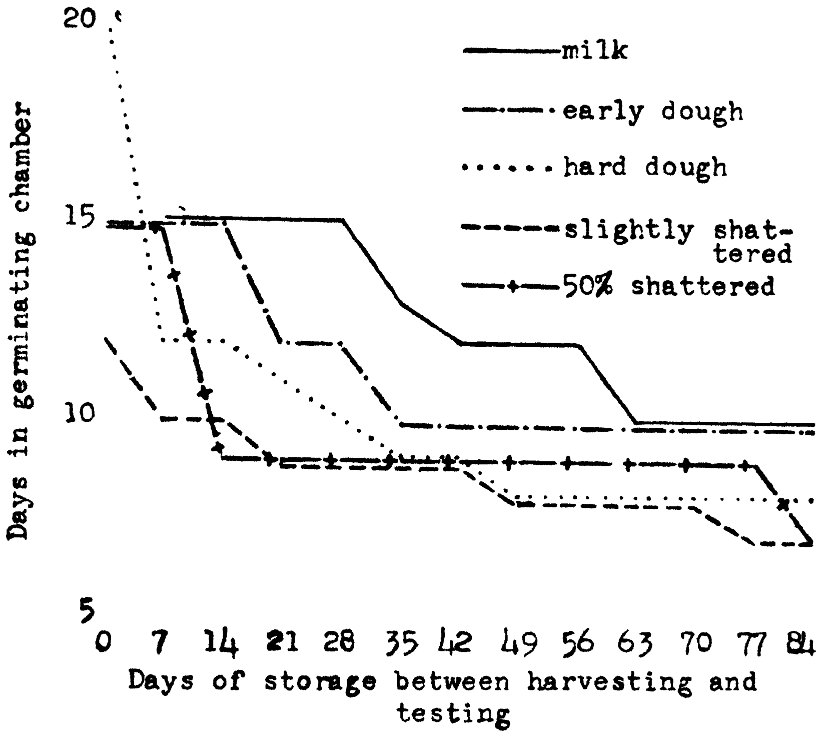

FIG. 1.— Relation between the maturity and the time required for germination of seed of *Agropyron cristatum*.

degrees of maturity. In general, the mature seed germinated more quickly after harvest and required less time than immature seed. Ten days were necessary for seed in the early dough stage, while the more mature seed germinated in seven days after storage for several weeks. Reference to Table 1 shows that seed which had reached hard dough development was the most immature seed to germinate readily when tested immediately after harvest. The hard dough seed required

more time to germinate when tested immediately after harvest than did less mature seed, but this discrepancy is probably explained by the much higher germination of the hard dough seed. Seed which had been harvested after 50% had shattered was slower in germinating than seed which had been harvested earlier. Probably the seed which germinates more quickly also shatters more quickly than less vigorous seed. This would be in accordance with general observations in cereals and corn.

EFFECT OF PRECHILLING UPON GERMINATION

In order to determine the effect of prechilling on germination of seed of different maturity, tests were made in which the seed was placed at 8° to 10° C in dampened towels for seven days before being germinated at 20° C. The prechilling tests were conducted immediately after harvest and again five weeks later. The germination of seed which had been prechilled was compared with the germination of seed in which the test was started at the time the prechilling was begun and with that in which the test was started simultaneously with the transfer of the prechilled seed to 20° C (Table 2).

TABLE 2.—*Relation between the maturity and the response to prechilling before germination of seed of Agropyron cristatum.*

Stage of maturity at harvest	Number of days between harvesting and testing*					
	0	7		35	42	
	%	Dry stored† %	Pre-chilled‡ %	Dry stored %	Dry stored† %	Pre chilled‡ %
Premilk	0	0	0	0	- -	- -
Early milk	0	0	0	4±1	5±1	19±2
Milk	0	1	0	28±2	22±3	27±1
Late milk	1	1	0	63±2	46±2	72±2
Early dough	2±1	38±3	7±2	85±2	85±1	85±2
Soft dough	3±1	59±2	4±1	88±1	86±1	86±2
Hard dough	53±2	63±1	83±1	88±2	92±1	94±1
Ripe	77±2	87±3	92±1	91±2	91±1	95±1
Slightly shattered	73±3	87±1	91±2	89±1	84±3	93±1
Shattered 50%	74±3	78±1	91±1	92±1	91±1	94±2

*Tests were made at 20° C between paper towels, using four lots of 100 seeds each.
†Stored dry at room temperature instead of being prechilled.
‡Held at 8° to 10° C between damp towels for seven days.

Chilling produced varying results with seed of different maturity. Through the late milk stage, germination did not occur in either chilled or unchilled seed during the first two weeks after harvest. In the earlier tests seed in the early dough and soft dough development was definitely retarded by chilling, as germination was much higher in seed which had been stored dry for one week than in seed which was chilled for a similar period. Seed in the hard dough stage showed a considerable increase in germination when chilled for seven days as compared with the germination when stored dry for one week. However, reference to Table 1 shows that a second week of dry storage resulted in germination comparable to that in the chilled seed. Ripe

and slightly shattered seed showed no significant differences between chilled seed and seed which had been stored for one week, but the seed which had shattered 50% germinated better after prechilling than after storage for one week, but not better than after two weeks of storage. Hay (2, 3, 4) has reported that prechilling increased germination in freshly harvested Montana-grown crested wheatgrass seed of 1935, which is in accordance with the results reported here for seed of the hard dough and to a lesser extent for seed of more advanced stages

After storage for five weeks, only seed in the early milk stage displayed a consistently favorable response to prechilling. Seed of certain other harvests showed no increased percentage of germination as a result of prechilling, while increases in the remainder were of only slight significance.

TEMPERATURE OF GERMINATION

Tests were made of seed harvested at four degrees of maturity to study the differential response to different temperatures during germination. Seed used in the study had been stored for 225 days. The seed was tested at alternating temperatures of 10° C for 16 hours and 20° C for 8 hours daily, and of 20° C for 16 hours and 30° C for 8 hours daily, and at constant temperatures of 10° C, 15° C, 20° C, and 30° C.

Because seed of *Agropyron cristatum* is often subjected to low temperatures under field conditions, another test was made in which the seed was held at 0° to 2° C for one week before being germinated at 20° C (Table 3)

TABLE 3 --*Relation between the maturity and the germination at different temperatures of seed of Agropyron cristatum.*

Stages of maturity at harvest	Germination* at given temperatures, %						
	Prechilled at 0 2° C for 7 days, constant 20° C	Not prechilled					
		Constant				Alternating	
		10° C	15° C	20° C	30° C	10° 20° C	20°–30° C
Early dough	15±2	88±1	90±2	84±1	89±1	90±1	88±1
Hard dough	74±2	92±1	95±1	94±1	94±1	94±1	96±1
Slightly shattered	90±2	95±1	96±1	92±2	95±1	93±1	91±1
Shattered 50%	82±3	90±2	95±1	92±2	89±2	89±2	89±2

*Tests were made between paper towels in four lots of 100 seeds

Alternation of temperatures was not effective in changing germination in any of the material tested. Chilling of the seed at the beginning of germination caused a reduction of nearly 70% in germination of the early dough seed and of nearly 20% in the hard dough seed. Other differences which resulted were of too little significance to be conclusive. Slight decreases in germination at 20° C after chilling, at 10° C, and at 30° C were shown by the most mature seed. Seed which had been harvested when slightly shattered germinated better than seed of any other harvest, and equally well at different temperatures.

RESERVE FOOD IN ENDOSPERM

To obtain an indication of the amount of reserve food in the endosperm of the seeds, observations were made of the seed weights, of the emergence of seedlings from different depths of planting, and of the heights reached by seedlings grown in darkness (Table 4).

TABLE 4.—*Relation between the maturity and the apparent amount of reserve food in the endosperm of seed of Agropyron cristatum.*

Stages of maturity at harvest	Average weight per 100 seeds, grams	Percentages of emergence from given depths					Heights of seedlings grown in darkness, cm
		½ in.	1 in.	1½ in.	2 in.	3 in.	
Early milk	————	4±1	8±4	0	0	0	36±5
Milk..	.1688±.0004	17±1	10±1	2±1	1	0	45±5
Late milk	.1898±.0003	14±1	15±1	1	0	0	60±5
Early dough	.2426±.0018	43±1	46±1	3±1	2±1	0	83±8
Soft dough	.2506±.0019	46±1	37±5	10±1	3±1	0	75±4
Hard dough	.2949±.0034	58±4	60±1	32±4	18±5	0	109±5
Ripe	.3006±.0010	71±5	66±1	35±3	18±6	1	106±5
Slightly shattered	.3047±.0028	82±1	76±2	43±8	22±4	0	113±4

Between six and seven months after harvest, seed of each stage of maturity was weighed in four lots of 100 seeds each and the average weights per 100 seeds were determined.

Duplicate lots of 66 seeds each for each harvest were planted in Palouse silt loam in greenhouse flats at depths of ½, 1, 1½, 2, and 3 inches and the number of emerging seedlings counted for each depth. Observations were made of the lengths of the coleoptiles and of the color and general vigor of emergent seedlings. Non-emergent seedlings were uncovered and examined to determine the reason for failure to emerge.

Fifty seeds of each harvest were planted at ¼-inch depths in Palouse silt loam and were grown in darkness until deterioration of the seedlings became apparent, when the heights of the seedlings were measured.

Corresponding differences appeared in seed weights, emergence in soil, and heights of seedlings grown in darkness. Weights per 100 seeds increased with maturity for seed of each harvest through the hard dough, beyond which only increases of slight significance occurred.

In all cases emergence was better from the ½- and 1-inch depths than from deeper plantings and failed or was negligible from the 3-inch depth. Lack of vigor of seed up to and including that of the late milk development was shown by general failure of emergence at more than 1 inch and by low emergence percentages at the shallow depths. Emergence was considerably greater from ½- and 1-inch plantings for the early dough and soft dough stages, but was very small from depths of 1½ inches or more. In seed of the hard dough and more mature stages, as compared with less mature seed, greater vigor was shown by the better emergence from the deeper plantings. Little difference is shown in emergence at 2 inches of hard dough

seed, ripe seed, and slightly shattered seed, but shallow plantings showed more variation. Emergence of the more mature seed at the various depths of planting is in accord with the results of Kirk, Stevenson, and Clarke (7), Love and Hanson (10), and Murphy and Arny (11) who worked with mature seed. Seedlings produced from seeds of the earlier harvests were observed to be distinctly weak and chlorotic when compared with seedlings developed from seeds of the later harvests.

In all cases of non-emergence, germination was as good as in laboratory tests, but the seedlings did not appear because the coleoptiles failed to elongate sufficiently to break the soil surface. When the coleoptiles stopped elongating, they were ruptured by the plumules which spread out under the surface of the soil. Kirk, Stevenson, and Clarke (7) have likewise reported this response in crested wheatgrass.

Apparently the maximum length of the coleoptile is closely associated with the endosperm reserve of the seed for non-emergence of seed of all degrees of maturity for which tests were made was due to lack of coleoptile elongation rather than lack of germination.

When planted at a ¼-inch depth and grown in complete darkness, the seed germinated about as well as between paper towels. Chlorophyll failed to develop and 20 days after planting deterioration of the seedlings became evident. Final heights of the seedlings increased with maturity of the seed through that in the hard dough. Among seed of the hard dough stage and seed of subsequent harvests there were no significant differences in final heights.

CONCLUSIONS

These investigations indicate that seed of *Agropyron cristatum* harvested in the early dough stage of development may have high viability but that vigorous plants probably can not be expected from seed harvested earlier than in the hard dough stage At favorable temperatures, germination and vigor of hard dough seed is as good as in more mature seed, but a decrease of germination in hard dough seed chilled for a week indicated that this may be slightly less hardy than more mature seed.

SUMMARY

Spikes of a 3-year-old stand of *Agropyron cristatum* were tagged with the date of anther exsertion and harvested at regular intervals from nine days after anther exsertion until the seed was 50% shattered.

Germination tests were made at 20° C of seed from each harvest immediately after harvesting, at weekly intervals for 11 weeks, and at irregular intervals thereafter up to 525 days. These tests showed that seed of *Agropyron cristatum* did not germinate well immediately after harvest, but that storage of the seed resulted in increased and accelerated germination. The storage period necessary for good germination was shorter in more mature seed. Both the germination immediately after harvest and the maximum germination after storage were higher as maturity increased. Likewise, the amount of time required for the completion of germination decreased with both

maturing and storage of the seed. Seed in the early dough stage reached a maximum germination nearly equal to that of later stages, but the storage period necessary to reach a maximum and the time required to complete germination were both longer.

Germination tests were made in which seed from each harvest was chilled at 8° to 10° C for one week before being germinated at 20° C. In seed which had been stored for five weeks, the low temperature had very little effect. In seed tested immediately after harvest, low temperatures reduced germination in seed up to and including that in the soft dough development, stimulated germination in seed in the hard dough, and had little more effect than a week of dry storage in more mature seed except in that which was heavily shattered.

Seed of each of several degrees of maturity which had been stored several months was germinated at several different temperatures, and at a favorable temperature after being chilled for seven days. Except for less mature seed which showed decreased germination following a week at very low temperatures, differences in germination of only slight significance were obtained at the different temperatures.

Observations were made of seed weights, of percentages of emergence from different depths of planting, and of heights of seedlings grown in darkness. These increased with greater maturity of the seed, but the increases were not large in seed harvested after reaching the hard dough stage. Best depth of planting appeared to be less than 1 inch, while only the more mature seeds produced emergent seedlings at the 2-inch depth and very little emergence occurred from 3 inches.

The investigations indicated that seed of high viability may be obtained by harvesting as soon as the early dough development, but that vigorous seedlings could not be expected from seed harvested earlier than when in the hard dough stage.

LITERATURE CITED

1. COLLINS, G. N. The application of statistical methods to seed testing. U. S. D. A. Circ. 79:1–18. 1929.
2. HAY, W. D. Germination of crested wheatgrass (*Agropyron cristatum*): preliminary studies. Proc. Assoc. Off. Seed Anal. N. Amer., 1935:66–70. 1936.
3. ————. Germination of crested wheatgrass and slender wheatgrass. News Letter, Assoc. Off. Seed Anal. N. Amer., 10 (1):3. 1936.
4. ————. Further studies with the germination of crested wheatgrass. Proc. Assoc. Off. Seed Anal. N. Amer., 1936:86–88. 1937.
5. KIESSELBACH, T. A. Effects of age, size, and source of seed on the corn crop. Nebr. Agr. Exp. Sta. Bul. 305:1–16. 1937.
6. ———— and HELM, C. A. Relation of size of seed and sprout value to the yield of small grain crops. Nebr. Agr. Exp. Sta. Bul. 11:1–73. 1917.
7. KIRK, L. E., STEVENSON, T. M., and CLARKE, S. E. Crested wheatgrass. Canadian Dept. Agr. Pamph. 157:1–22. 1934.
8. LEGGATT, C. W. Contributions to the study of the statistics of seed testing. II. The X^2 test as a basis for computing germination tolerances. Proc. Intern. Seed. Test. Assoc., 7:38–48. 1935.
9. LOVE, H. H. Application of Statistical Methods to Agricultural Research. Shanghai, China: Commercial Press, Ltd. 1936.
10. LOVE, L. DUDLEY, and HANSON, HERBERT C. Life history and habits of crested wheatgrass. Jour. Agr. Res., 45:371–383. 1932.

11. MURPHY, R. P., and ARNY, A. C. The emergence of grass and legume seedlings planted at different depths in five soil types. Jour. Amer. Soc. Agron., 31:17–28. 1939.
12. SALISBURY, E. J. The biological equipment of species in relation to competition. Jour. Ecol., 17:197–222. 1929.

HEAT CONDUCTIVITY AS AN INDEX OF SOIL MOISTURE[1]

BYRON SHAW AND L. D. BAVER[2]

ELECTRICAL conductivity methods of measuring soil moisture have failed because the conductivity of the soil at a given moisture content vaires greatly with changes in the salt concentration of the soil solution. A successful method of measuring changes in soil moisture will necessarily be one that uses some property of the soil and the soil solution that is not influenced by changes in the salt content. Heat conductivity should be a property of such a system which would not be materially affected by the presence of ions in solution, since rather large changes in the concentration of a dilute salt solution have very little influence on the thermal conductivity.

The heat conductivity of a dry porous medium, such as soil, must of necessity be low, since the solid materials make only point contacts. The area for continuous heat flow through soil materials is very small. A negligible amount of the heat is conducted by the air in the pores, since air is a much poorer conductor than the soil solids. As water is added to the soil, the area through which heat can flow will increase tremendously since the water will form wedges around the points of contact. Water is not as good a conductor of heat as the solid soil material, but it is a far better conductor than air. Thus, it is to be expected that the heat conductivity of a soil will increase with its moisture content. The investigations of Patten[3] bear out this conclusion.

In view of the above considerations, an investigation of the heat conductivity of soil was undertaken with the following objectives: (1) To find a relatively simple method of measuring the changes in heat conductivity of a soil at various moisture contents; (2) to study the relationship between heat conductivity and moisture content; (3) to verify the conclusion that variations in the concentration of salts in the soil solution will not affect the conductivity of heat, and (4) to study the possibilities of using heat conductivity as an index of the changing moisture conditions of the soil *in situ*.

The instrument devised for measuring the changes in heat conductivity of a soil at varying moisture contents is shown diagrammatically in Fig. 1. It is an adaptation of the Wheatstone bridge. R_1 is a fixed manganin resistance of about 7 ohms; R_2 is a variable resistance box; B and C are the other two arms of the bridge. They consist of equiresistant coils (about 8 ohms) of No. 40 enameled copper wire wound on 6-mm glass tubing. Leads of large copper wire go through the walls of the glass tubing and are soldered to the fine wire. The tubes are sealed water tight. These coils are held stationary by tightly fitting water proof plugs in the bottom of ¾-inch circular chambers drilled through a cylindrical brass block 3 inches in diameter and 3 inches high. The chambers are closed at the top by rubber stoppers. The brass block is used to maintain equal external condi-

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[3]PATTEN, H. E. Heat transference in soils. U. S. D. A. Bur. Soils Bul. 59.

tions for both coils and thus to eliminate the necessity of a constant room temperature. The chamber containing coil C is filled with oven-dry soil and the other chamber is filled with soil differing from that in the first only in moisture content. The brass block is tapped 50 times with a hammer to insure a packing of the soil in the chambers that can be duplicated, and also to establish intimate contact with the coils. The bridge is first balanced with dry soil in each chamber. The balance is obtained by varying R_2 until the galvanometer shows no deflection. The total current through the bridge is kept constant at 0.4 ampere.

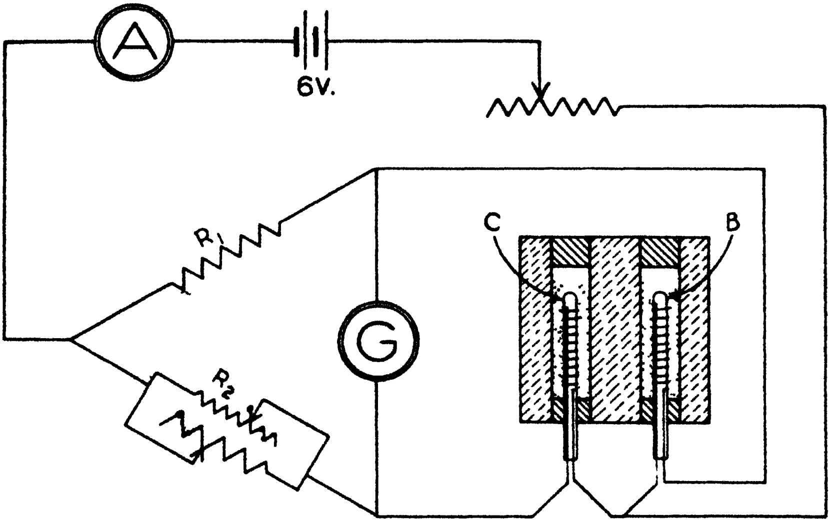

FIG. 1.—Heat conductivity apparatus.

Since the resistance of a copper wire increases with its temperature, the resistances of coils B and C are dependent upon the conductivity of the soil surrounding them. If the heat conductivity of the soil in each chamber is the same, the bridge will remain balanced in spite of the fact the temperature of both coils is continually rising. The resistances of R_1 and R_2 are not affected by temperature changes. Since the copper coils are equally resistant to the flow of electricity they gain heat at the same rate, and inasmuch as the heat conductivities of the materials surrounding the coils are equal, they also lose heat at the same rate. Thus, the temperatures of the two coils remain equal and so it follows that their resistances also stay equal. When the temperature of the coils rises to the point that heat is lost as fast as it is gained, the temperature rise stops

It can be seen that if the soils in the two chambers have different heat conductivities, the final equilibrium temperatures of the coils will be different. The coil in the material of lowest heat conductivity will have the highest temperature and also the highest resistance. In order for the bridge to be put in balance it is necessary to change the value of R_2. This change from the original value reflects the difference

between the resistances of B and C and, since these resistances are determined by the temperature of the coils, the change is also a measure of the difference between the heat conductivities of the materials in the two chambers. It is not necessary to keep the current flowing through the bridge until the equilibrium condition is reached so long as some standard procedure is adopted for all determinations. If the bridge is balanced with dry soil in each chamber it will still be in balance, as long as no current flows, regardless of the moisture content of the soil in the chamber containing coil B. When the current is turned on the bridge is immediately thrown out of balance due to the unequal rates of temperature rise in the two coils. The maximum displacement from the balance occurs at the time the equilibrium temperatures are reached, but the displacement obtained at an arbitrary time after the current is turned on is equally as representative of the heat conductivities of the soils in the two chambers as is the displacement at equilibrium. An advantage in using a short time interval comes from the fact that in the chamber containing the moist soil, the moisture begins to move away from the coil as soon as the element begins to heat up. Approximately 10 calories of heat are developed at the coil in 2 minutes. This amount of heat is not large enough to cause any appreciable moisture movement since it causes only a very small increase in the temperature of the coil. Readings can be duplicated in from 10 to 15 minutes, or at such time as the coils have again cooled down to equal temperatures.

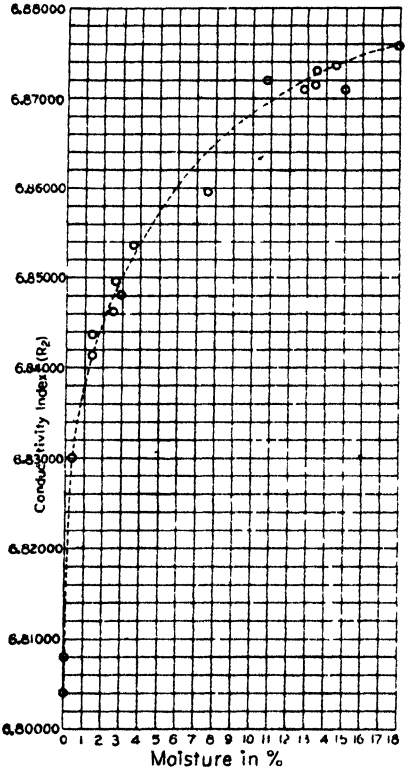

FIG. 2.—Heat conductivity-moisture curve for quartz sand.

The sensitivity of the instrument is very nearly proportional to the cube of the current flowing through the bridge. It is very important, therefore, to keep the current constant during the course of a determination. In a series of measurements in which moisture content is to be the only variable it is important to have the same packing of the soil around the element in each case. This is not easily achieved since the chamber containing the moist soil must be refilled for each different moisture content. The procedure followed consists in using a weight of soil in the moist chamber which contains an amount of oven dry soil equivalent to that in the dry chamber. The

brass block is then tapped 50 times with a hammer. This tapping compacts the soil and makes the volumes very nearly equal. Moist soils have a tendency to occlude air as well as to swell. These factors complicate the packing problem to such a degree that it is not possible to obtain the same compactness in every instance. As a general rule the samples of higher moisture content were packed more loosely.

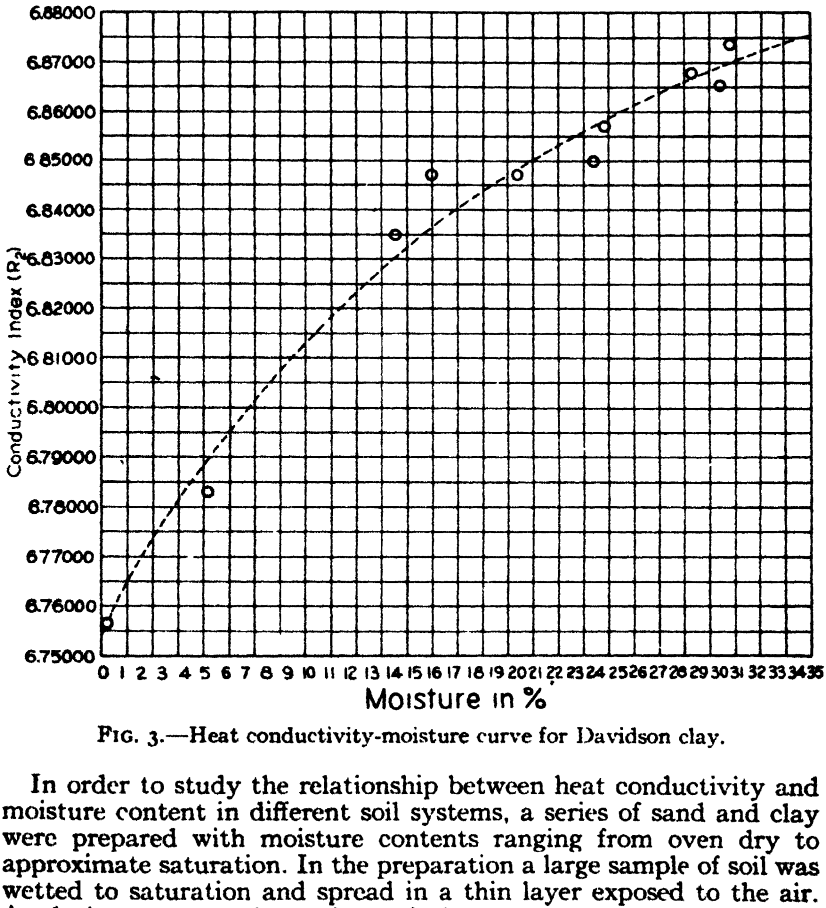

FIG. 3.—Heat conductivity-moisture curve for Davidson clay.

In order to study the relationship between heat conductivity and moisture content in different soil systems, a series of sand and clay were prepared with moisture contents ranging from oven dry to approximate saturation. In the preparation a large sample of soil was wetted to saturation and spread in a thin layer exposed to the air. As drying progressed, portions of about 100 grams were taken at intervals sufficiently long to insure different moisture contents. These were placed in air-tight containers and vigorously shaken every day for a period of two weeks. At this time the moisture distribution was very nearly uniform. Two samples were taken from a container at the time a heat conductivity determination was to be made. One was placed in the moist chamber of the apparatus and the other was used to determine the moisture content. During the filling of the apparatus both samples were exposed to the air for equal times. After the chamber was filled and stoppered, it was allowed to stand 30 minutes be-

fore a reading was taken. In this time interval the soil came into temperature equilibrium with the brass block. Readings were taken 2 minutes after the current was turned on.

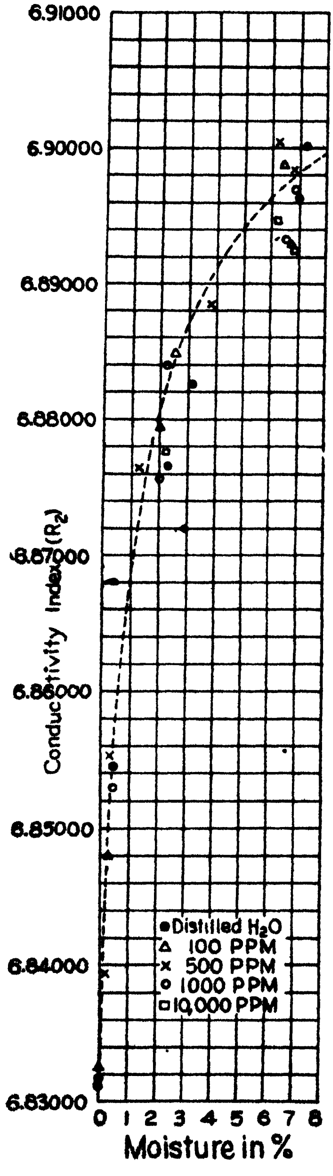

FIG. 4.—Heat conductivity-moisture curve for sand-salt system.

The relationship existing between the indicating resistance (R_2) and moisture content for the quartz sand series is shown in Fig. 2. The steepness of the curve in the low moisture range shows the rapidity with which heat conductivity increases with moisture. This is a natural expectation. In the dry state the sand grains make only relatively few paths of point size cross section for heat flow through the system. Since sand is able to hold only a very slight amount of hygroscopic water, the added water takes the form of wedges around the points of contact. The effective area through which heat can flow is increased tremendously with only small additions of water. As the pores fill with water the effective area is further increased, but the rate of increase becomes less rapid. It is evident that the portion of the curve showing greatest sensitivity extends from zero moisture to above field capacity.

A curve connecting the values of R_2 plotted against moisture content for the Davidson clay series is shown in Fig. 3. The curve does not show the initial rapid rise that was in evidence with sand. This can be explained on the basis of particle size and associated properties. Clay affords many more paths for heat flow in the dry state than sand. Since clay holds a relatively large amount of hygroscopic water, the first additions of water are not as effective in increasing the area through which heat can flow as they were with the sand. The water wedges are built up gradually and this leads to a gradual increase in heat conductivity. The greater variety of pore sizes and greater total pore space in clay lead to a more gradual increase in heat conductivity and also to a greater difference between the conductivity of dry and saturated soil.

Having established the fact that heat conductivity does give an index

of the moisture content of the soil, it is essential to know if the salt concentration of the soil solution affects the results. Five series of quartz sand were prepared having different concentrations of salt in the soil solution. Uniformly distributed moisture was obtained by the method described above. The first series was wetted with distilled water, the second with water containing 100 p.p.m. NaCl, the third with water containing 500 p.p.m. NaCl, the fourth with water containing 1,000 p.p.m. NaCl, and the fifth with water containing 10,000 p.p.m. NaCl. This range extends beyond the limits of salt content found in ordinary soils. The effect of the different concentrations of salt on the conductivity of heat is shown graphically in Fig. 4. While there is considerable scattering of the points from the smooth curve, the variations can in no way be correlated with salt content. The curve drawn fits the data obtained from one series equally as well as the data from any other. The scatter of points is due largely to variations in packing and variations in current. The changes in surface tension associated with differences in salt content increase the difficulty of obtaining the same degree of packing in the wet systems. It appears safe to conclude that changing salt concentrations in the soil solution will not materially affect the heat conductivity at a particular moisture content.

CONCLUSION

The results of these studies point out that the first three objectives of this investigation have been achieved, namely, (1) it has been possible to devise an apparatus for measuring changes in the heat conductivity of a soil at various moisture contents; (2) it has been established that heat conductivity gives a reliable index of the moisture content of the soil; and (3) it has been shown that changes in salt concentration of the soil solution do not materially affect the heat conductivity of the soil.

Work is now in progress to achieve the fourth objective, that is, to adapt the principle of heat conductivity to measuring the moisture of the soil *in situ*. The results of this phase of the investigation will be discussed in a later paper.

EFFECT OF REMOVING DIFFERENT PROPORTIONS OF FOLIAGE ON CONTRASTING STRAINS OF KENTUCKY BLUEGRASS, *POA PRATENSIS* L.[1]

A. O. KUHN AND W. B. KEMP[2]

THERE are many species and strains of grass existing in pastures. It has been shown that strains within a species may vary widely in their morphological characteristics such as height of growth. The effect of height of clipping on various grasses has been studied, but there is no evidence that an attempt has been made to compare various strains of a species when an equal proportion of foliage is removed from all plants.

Investigators (2, 3, 6, 8, 10)[3] have shown that different species react differently to variations in intensity of clipping. In general, investigations (1, 2, 4, 5, 7, 9, 11) into the production of forage by Kentucky bluegrass have shown that the amount of growth below the surface of the ground and the total weight of top growth tend to vary inversely with the frequency and intensity of defoliation.

This paper deals with a comparison between one strain of Kentucky bluegrass which is tall-growing and another which is unusually low-growing, when like proportions of foliage are removed from each.

METHODS

Two strains of Kentucky bluegrass from the Maryland Experiment Station selections were used in this experiment. They were designated as strain 10-3 and strain 12-4. Strain 10-3 came originally from a field where bluegrass had grown for at least 50 years under conditions of little grazing. It is a tall-growing plant (Fig. 1). Strain 12-4 was obtained originally from an alley on the Maryland Experiment Station farm. The alley had been kept closely clipped and subjected to heavy traffic throughout the summer months. This strain is an extremely low-growing type. These strains had been maintained in the grass gardens at College Park under uniform soil conditions for three years prior to their use in the experiment herein reported.

Thirty plants of each strain were taken from among small, uniform, rooted rhizomes and potted in the greenhouse in February. These pots were 7 inches in diameter and 5½ inches deep and contained a sandy loam soil. When the plants had become established in the greenhouse, the pots containing the 24 most uniform plants of each type were selected and placed in the open on a table which was constructed as a watertight basin in order that water might be supplied to the pots. The plants remained on this table throughout the experiment. There were five cutting treatments used, each of which was replicated four times. The clipping point in each type of treatment was none, mid-blade, 1-inch beyond ligule, at ligule, and below ligule.

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[3]Figures in parenthesis refer to "Literature Cited", p. 895.

FIG. 1.—Appearance of comparable young plants of contrasting strains of Kentucky bluegrass. *Left*, strain 10–3; *right*, strain 12–4.

Each individual blade of each plant was clipped separately to insure uniform proportionate removals. Clippings were made at two-week intervals beginning April 28. All of the seed and seed stalks were removed on June 15. All of the clippings obtained during the season and the entire plants remaining at the end of the treatments were placed in an oven at 100° F for one week, before weighing. The average height that each removal of clippings actually constituted was determined by a number of measurements of the tops remaining after clippings were made.

EXPERIMENTAL RESULTS

When the same proportions of foliage were removed from each of the two contrasting strains of Kentucky bluegrass, the tall-growing and the short-growing one, increase in severity of defoliation caused a similar and highly significant decrease in the production of roots, rhizomes, and tops (Table 1). The weight of clippings obtained during the season also decreased equally on the two strains with increase in severity of defoliation.

When the comparison between the two strains was based on comparable heights of clipping rather than comparable proportion removed from the plant, there were striking differences between them (Table 2). A mean height of 1.40 inches resulted when strain 10–3, the tall-growing one, was clipped just above the ligule, while a comparable height of 1.60 inches resulted when strain 12–4, the short-growing one, was left unclipped. At these heights of top growth remaining on the plant after clipping, strain 12–4 produced approximately one and a half times as much weight of tops, more than five times as much weight of roots, and more than eight times as much weight of rhizomes as strain 10–3.

TABLE 1.—*Effect of severity of clipping on weight of plant material produced by contrasting strains of Kentucky bluegrass, 1938.*

Clipping point on blade	Mean height after clipping, inches	Production in grams			
		Roots	Rhizomes	Forage	Total
		Strain 10-3 (Tall-growing)			
None	3.92	67.1	27.0	69.84	163.94
Mid-blade	2.27	31.8	20.4	64.59	116.79
Inch beyond ligule	2.05	26.1	11.2	49.32	86.62
At ligule	1.40	8.84	4.85	38.77	52.49
Below ligule	1.07	6.84	3.47	35.21	45.52
		Strain 12-4 (Low-growing)			
None	1.60	49.2	39.3	53.50	142.00
Inch beyond ligule*	1.17	27.0	27.3	51.09	105.39
Mid-blade*	0.90	21.9	13.0	51.42	86.32
At ligule	0.40	9.70	5.68	38.11	53.49
Below ligule	0.20	5.74	2.50	27.52	35.76

*Treatments reversed because clipping at mid-blade was less than 1 inch from ligule.

TABLE 2.—*The responses of two contrasting strains of Kentucky bluegrass to comparable heights of clipping.*

Strain 10-3		Strain 12-4	
Height, inches	Weight, grams	Height, inches	Weight, grams
	Production of Tops*		
1.40	38.77	1.60	53.50
1.07	35.21	0.90	51.42
	Production of Roots		
1.40	8.84	1.60	49.20
1.07	6.84	0.90	21.90
	Production of Rhizomes		
1.40	4.85	1.60	39.30
1.07	3.47	0.90	13.00

*Includes both harvested material and top growth remaining when plants were removed from soil.

When strain 10–3 was clipped just below the ligule a mean height of 1.07 inches resulted while clipping strain 12–4 so as to remove half of the blade resulted in a comparable height of 0.90 inch. At these heights of top growth remaining after clipping, strain 12–4 produced nearly twice as much weight of tops, three times as much weight of roots, and nearly four times as much weight of rhizomes as strain 10–3.

SUMMARY AND CONCLUSIONS

Two strains of Kentucky bluegrass of contrasting habit with respect to height of growth were compared when like proportions of foliage were removed from each. Increase in severity of defoliation caused a similar and highly significant decrease in the production of roots, rhizomes, and tops.

When comparisons between the two strains were based on comparable height of clipping rather than comparable proportions of the foliage removed, the short-growing strain when clipped either at approximately 1½ inches or at 1 inch produced strikingly more tops, roots, and rhizomes than the tall-growing one.

LITERATURE CITED

1. ALBERT, W. B. Studies on the growth of alfalfa and some perennial grasses. Jour. Amer. Soc. Agron., 19:624–654. 1927.
2. ALDOUS, A. E. Effect of different clipping treatments on the yield and vigor of prairie grass vegetation. Ecology, 11:752–759. 1930.
3. BISWELL, H., and WEAVER, J. E. Effect of frequent clipping on the development of roots and tops of grasses in prairie sod. Ecology, 14:368–390. 1933.
4. ELLET, W. B., and CARRIER, L. The effect of frequent clipping on total yield and composition of grasses. Jour. Amer. Soc. Agron., 7:85–87. 1915.
5. GRABER, L. F. Penalties of low food reserves in pasture grasses. Jour. Amer. Soc. Agron., 21:29–34. 1929.
6. ————, et. al. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wisc. Agr. Exp. Sta. Bul. 80. 1927.
7. HARRISON, C. M. Responses of Kentucky bluegrass to variations in temperature, light, cutting, and fertility. Plant Phys., 9:83–106. 1934.
8. ———— and HODGSON, C. W. Response of certain perennial grasses to cutting treatments. Jour. Amer. Soc. Agron., 31:418–430. 1939.
9. MORTIMER, G. B., and AHLGREN, H. L. Influence of fertilization, irrigation and stage and height of cutting on yield and composition of Kentucky bluegrass. Jour. Amer. Soc. Agron., 28:515–533. 1936.
10. WIGGANS, R. G. Studies of various factors influencing the yield and duration of meadow and pasture plants. Cornell Univ. Agr. Exp. Sta. Bul. 424. 1923.
11. WOLFE, T. K. The yield of various pasture plants at different periods when harvested as pasturage and as hay. Jour. Amer. Soc. Agron., 18:381–384. 1926.

NOTES

LONG-TIME STORAGE OF WINTER WHEAT

MANY investigations have been carried on to determine what factors enter into the successful long-time storage of wheat on farms. There has also been much discussion as to the length of time wheat can be stored and still remain viable or usable for milling purposes. The opportunity to secure some information on these questions became available in July, 1938, when a local elevator at Norcature, Kans., purchased 800 bushels of hard winter wheat of the Turkey variety from a crop harvested in 1927 and which had been stored in a farm steel bin for 11 years. The writer secured a sample for milling and baking determinations and also interviewed the grower.

The wheat had been grown by L. P. Montgomery, Clayton, Kans., in 1927 on land that had produced corn in 1926. The 800 bushels were combined when the weather was dry and hot and stored immediately in a 1,000-bushel steel bin. The bin was of tight construction except for a ventilator running from the outside along the floor to a center vertical perforated 6-inch tube having an outlet 10 inches above the top of the bin. The moisture content of the wheat at the time it was stored was not known, but the conditions under which it was combined would indicate that it was well below 12%. When sold in 1938 the moisture content was about 11%

The wheat was never turned, ventilated, or moved in any manner, and at no time during the 11 years in storage did it show signs of heating. The wheat was never fumigated, but when removed from the bin in 1938 it showed no trace of any damage from insects or other causes. The grain contained traces of yellow berry and, in the main, was of good luster and almost free from cracked kernels. A sample of the 11-year-old wheat sown the fall of 1938 at the Fort Hays Experiment Station produced a stand equal to that from new-grown seed of the same variety. Seed planted in soil in the greenhouse germinated 53%.

The rainfall and temperatures fluctuated very widely during the period from 1927 to 1938. For instance, the seasonal rainfall at Hays, Kans., which corresponds very closely to that of the region in which the 11-year-old wheat grew, varied from 12.8 to 26.5 inches. The season of 1932 was extremely humid, while the seasons of 1933 to 1936 were noted for extreme temperatures and low rainfall during the summer months. Periods of low temperature with much snow also occurred in the region during the 11 years. Since the wheat was apparently stored when thoroughly dry and of low moisture content, free from weevils, and relatively free from cracked grain, the fluctuations in atmospheric moisture and temperatures were never sufficient to cause the grain to go out of condition.

Milling and baking data were secured on the 11-year-old wheat through the courtesy of L. E. Leatherock, Chief Milling Chemist for the Kansas Milling Company, Wichita, Kans. The wheat had a test weight of 60.7 pounds per bushel, 11.0% moisture, and 11.33% protein, and milled out 71.6% total flour. The flour showed 0.496% ash,

10.00% protein, and 14.1% moisture, and was given a color score of 100 gray. The water absorption of the flour was 62.0%, the loaf volume 645 cc. The crumb color was graded as 100.5 gray white, with a texture of 99.0. Further notes indicate that the wheat milled satisfactorily considering its age, that it baked a good loaf of bread, and that the flour gave a dough with a long mixing time and excellent mixing tolerance. The milling and baking results compared favorably with those of the adapted varieties grown in the same region in 1938. —A. F. Swanson, *Fort Hays Experiment Station, Hays, Kansas.*

AN APPARATUS DESIGNED TO FACILITATE PHOTOGRAPHY OF SMALL MACROSCOPIC OBJECTS

IN plant research as well as other fields, photography is an almost indispensable tool for picturing accurately to others phenomena observed. However, too often lack of proper equipment to give the "camera's eye" the necessary detail has resulted in failure to reproduce effectively the phenomena actually seen by the worker.

The apparatus shown in Fig. 1 was designed to give a uniform lighting of sufficient intensity to allow for a long exposure necessary for good detail in photographic reproductions As can be seen in the photograph, this apparatus is essentially a box 30 by 36 inches and 20 inches high, mounted on rollers. On the top of the box is a ground-glass bottom tray with the same outside dimensions as the box and 3½ inches deep. This tray is water-proof and when objects such as root systems of plants are being photographed water is added to the tray. The roots flow out into a more normal position and have almost the same appearance that they would if they could be photographed in the soil. An example of this is shown in Fig. 2.

FIG. 1.—Photographic apparatus.

Lighting from below is supplied indirectly through the glass in the bottom of the tray thus eliminating minute shadows which have a tendency to cloud the detail. The light from photofloods (A) and (B) strikes the bottom of the box which has a highly polished surface and are reflected up through the glass bottom of the tray. Light from above is supplied by photofloods (C) and (D) which are mounted on double-jointed telescopic pipes which make adjustment to the desired height and angle easy.

FIG. 2.—Nodulation produced by root nodule bacteria on red clover.

The camera (E), in this case an Eastman (Recomar 33), is mounted with an optipod on a double-jointed telescopic pipe similar to the upper photofloods. This gives the camera a rigid mount and allows for easy manipulation for the proper height and centering of the object being photographed. The camera should have a groundglass focus which aids considerably in close-up photography.

This piece of equipment was constructed in our laboratory and has been used in photographing a wide variety of objects, including plant roots, stems, leaves and seeds, petri dishes showing colony growth of bacteria, copying graphs, and many other objects occupying an area ranging from 10 to 500 sq. in. and has given excellent results.

The approximate cost of construction, complete except for the camera, is about $20. Besides the saving in time and film, this equipment has more than paid for itself with photographs having greater detail and accuracy.—J. C. BURTON and L. W. ERDMAN, *The Nitragin Company, Inc., Milwaukee, Wis.*

BOOK REVIEWS

ELEMENTS OF PLANT PATHOLOGY

By Irving E. Melhus and George C. Kent. New York: The Macmillan Company. X+493 pages, illus. 1939. $4.

THIS is an excellent textbook for students who wish to complete their knowledge of plants. It will introduce to them the fact that plants do sicken, that they need medical assistance, that such assistance is available, and that it constitutes a branch of knowledge worthy of college attention.

The objects as set forth for the book are (1) to appreciate the influence of plant pathology on human affairs, (2) to acquire an understanding of health and disease in plants, (3) to understand the phenomena of parasitism, and (4) to acquire as much information as possible about the characteristics of diseases, their symptoms, cause, and control. A series of chapters deals with diseases classified according to cause including fungi, seed plants, nematodes, viruses, and nonparasitic agents. Reference to investigators is quite properly omitted in the interest of brevity and lucidity except where the name of the authority is of classical importance.

The authors have made a refreshing departure from the current practice of teaching plant pathology. They recognize that the subject is no longer just a study of organisms associated with sick plants. They have minimized the emphasis on mycology and have shifted it to parasitism. This, however, is chiefly a shift from taxonomy of the fungus to physiology. The fungus is still the major interest. Since the term, plant pathology, means a study of diseased plants, it is unfortunate that the authors did not complete the inevitable step and place the emphasis on the diseased plant itself, on its ability to withstand the disease, and on the factors that affect its ability to withstand disease. It seems that they might well have placed the emphasis where it is placed in animal pathology, on the organism that is diseased. In any case the text seems to warrant careful scrutiny by any teacher who needs a very readable, non-technical presentation of the present field of plant pathology. (J. G. H.)

GERMAN-ENGLISH SCIENCE DICTIONARY

By Louis de Vries. New York: McGraw-Hill Book Co., Inc. X+473 pages. 1939. $3.

THIS dictionary has been compiled for students in the agricultural, biological, and physical sciences. The author is Professor of Modern Languages at Iowa State College and had the collaboration of members of the Graduate Faculty in the preparation of this volume. Among these latter will be found several names familiar to agronomists, including J. M. Aikman in plant ecology, A. E. Brandt in statistics, R. E. Buchanan in bacteriology, R. M. Hixson in plant chemistry, E. W. Lindstrom in genetics, J. N. Martin in plant morphology and cytology, I. E. Melhus in plant pathology, F. B. Smith in agronomy, and others.

No attempt has been made to compile a complete list of names of all animals, plants, insects, or chemical compounds, but rather recourse has been had to the facility with which the German language lends itself to the compounding of words. In the 48,000 entries, therefore, stress has been placed on root stems from which the student can derive the meaning of almost any compound he would encounter. A list of abbreviations with both the German and English meanings is appended.

Well printed in a 5- by 7-inch size and with a flexible cover, the book makes an attractive and convenient volume for the student's desk. (J. D. L.)

GROWING PLANTS WITHOUT SOIL

By D. R. Matlin. New York: Chemical Pub. Co., Inc. VII+139 pages, illus. 1939. $2.

THIS is an enthusiastic (perhaps over-enthusiastic) discussion of the growing of plants in nutrient solutions. The over-enthusiasm of the author is shown by his statement that, "The greatest advantage of chemiculture lies in the direction of improving the quality of food products, of mineralizing the foods," etc. As an example of "mineralizing" foods, he states that "Dr. Charles Norther of Orlando, Florida, grew celery which upon chemical analysis showed twice the mineral content of the best grown elsewhere." The author seems to have overlooked the fact that the much publicized "mineralized" vegetables of Dr. Norther were grown in soil.

The first 46 pages of the book are devoted to a rambling but enthusiastic discussion of growing plants without soil highlighted by such startling statements as annual returns of $50,000 per tank-acre and the very low cost of the essential chemicals in 100-pound lots to show "why chemiculture is so inexpensive."

The remaining 91 pages are devoted to such unrelated subjects as making cuttings, hormones, budding, vitamins, list of state flowers, addresses of all agricultural experiment stations, and other miscellaneous material. (C. B. S.)

HANDBOOK OF CHEMISTRY

Compiled and edited by N. A. Lange, assisted by G. M. Forker and R. S. Burington, Sandusky, Ohio: Handbook Publishers, Inc. Ed. 3. XVIII+1850 pages. Fabricoid. 1939. $6.

THERE are several points which make this volume superior to all other works of its kind. The clearness of presentation as well as of the printing are beyond criticism in spite of the enormous quantity of information contained in the HANDBOOK. There is an increase of about 50 pages in the text and a small increase in the index.

The summarizing treatment of various groups of materials, as for instance the tables giving the melting point of various organic compounds, is of much help to the worker looking for general information on any subject. The quantity and variety of information included in

the volume make it not only useful but almost a necessary help to all dealing with the sciences. (Z.I.K.)

AGRONOMIC AFFAIRS

PROFESSOR SHAW, PROFESSOR MUSBACH, AND PROFESSOR HUTTON

SOIL science in general and the American Society of Agronomy and the Soil Science Society of America in particular lost three of its outstanding personalities during the past few weeks in the deaths of Professor Charles F. Shaw of the University of California, Professor F. L. Musbach of the University of Wisconsin, and Professor J. G. Hutton of South Dakota State College.

Professor Shaw died on September 12, following a brief illness. He had long been an active member of the American Society of Agronomy and also participated actively in the Soil Science Society of America, the International Society of Soil Science, and many other organizations.

Professor Musbach was killed in an automobile accident on September 14. He had been active in the American Society of Agronomy since the second year of its organization and at the time of his death was in charge of the soil investigations on the branch experiment stations of the University of Wisconsin.

Professor Hutton died at Brookings, South Dakota, on September 23. He had been continuously in the position of Associate Agronomist and later Professor of Soils in South Dakota State College, and in charge of soil research at the South Dakota Agricultural Experiment Station, since 1911. Just recently he published South Dakota Experiment Station Bulletin No. 325 entitled, "Thirty Years of Soil Fertility Investigations in South Dakota".

THE TRANSACTIONS OF THE THIRD COMMISSION

THE TRANSACTIONS of the meeting of the Third Commission of the International Society of Soil Science made its appearance just preceding the meeting of the Commission at New Brunswick, N. J., the latter part of August. The volume makes 185 pages and is paper covered.

Dedicated to Doctor J. G. Lipman, the volume opens with a tribute to Doctor Lipman by Doctor D. J. Hissink. There follows then the twenty-five papers presented before the Commission under the three general headings of "Legumes and Legume Bacteria," "Microbiology of Soil Organic Matter", and "Azotobacter and Its Significance in Soil Processes". A list of the papers on soil microbiology presented before the Third International Congress for Microbiology in New York City early in September is appended.

THE 1940 TOBACCO FERTILIZATION RECOMMENDATIONS

RECOMMENDATIONS for the fertilization of flue-cured, sun-cured, and shipping tobacco to be grown on average soils in Virginia, North and South Carolina, Georgia, and Florida in 1940 have been prepared by the joint Tobacco Research Committee of which Professor C. B. Williams of the North Carolina State College of Agriculture at Raleigh is chairman. The report is in mimeographed form and may be obtained upon request to Professor Williams.

ABSTRACTS OF LITERATURE PERTAINING TO BIOCLIMATOLOGY AND BIOMETEOROLOGY

ANNOUNCEMENT has been made by BIOLOGICAL ABSTRACTS of a more complete abstracting service and segregation of the current research literature in bioclimatology and biometeorology. A section entitled "Bioclimatology-Biometeorology" will soon appear within the section on "Ecology" in BIOLOGICAL ABSTRACTS, with Robert G. Stone of the Blue Hill Observatory, Harvard University, as editor.

ERRATUM

IN the article entitled "Heat Resistance in Oat Varieties" by Franklin A. Coffman, pages 811–817 in the September number of this JOURNAL, the word "inhibitional" in line 7, paragraph 2, under "Discussion" on page 816, should read "imbibitional".

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THE OXIDATION-REDUCTION POTENTIAL OF ALKALINE CALCAREOUS SOILS IN RELATION TO PUDDLING AND ORGANIC MATTER DECOMPOSITION[1]

T. F. Buehrer, W. P. Martin, and R. Q. Parks[2]

ALTHOUGH the study of redox potentials of soils has in recent years received attention at the hands of numerous investigators (1, 3, 8, 15, 18, 21, 23),[3] such studies have been confined almost entirely to soils of humid regions and to the behavior of soils under water-logged conditions. By way of contrast, the alkaline calcareous soils of the desert present certain characteristics which offer opportunity for application of the redox potential method. They contain an exceedingly active microflora and the decomposition of organic matter proceeds at a very rapid rate, as has been shown by Oberholzer (14). Because of their low organic matter content, such soils easily pass into the puddled state when cultivated under irrigation, as found by McGeorge (11). Under such circumstances anaerobic conditions have been shown to exist by Breazeale and McGeorge (4) with attendant loss of nitrogen by denitrification and serious inhibition of plant growth. These authors showed further that the incorporation of organic matter in a puddled soil will not of itself correct the puddled condition and that the toxic substances formed in the anaerobic decomposition are at times so stable that they are not readily oxidized to non-toxic forms when the soil is allowed to dry out and become thoroughly aerated.

It seemed of interest, therefore, to apply this method to some typical desert soils in their normal and puddled states, and in the presence and absence of actively decomposing organic matter. The present paper presents the results of certain phases of this investigation. For purposes of comparison a similar study was conducted on a typical soil from a humid region.

[1]Contribution from the Department of Agricultural Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Published with approval of the Director. Also presented before the Western Society of Soil Science, Stanford University, Palo Alto, Calif., June 26–28, 1939. Received for publication August 15, 1939.

[2]Physical Chemist, Assistant Soil Microbiologist, and Graduate Assistant, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 914.

METHOD OF Eh MEASUREMENT

The technic of measurement employed was substantially that of Brown (5), with certain modifications to make the method applicable to the soils being studied. The electrode system consisted of a bright platinum wire ***welded to the copper wire*** leading to the potentiometer, and a calomel cell made up with saturated potassium chloride and connected with the soil suspension by way of an agar bridge. The potentials were measured with a Leeds and Northrup potentiometer. The authors desire to emphasize at this point the difficulties which may be encountered when the conventional mercury contact between the platinum electrode and the potentiometer wire is employed. Very erratic potentials were obtained under these conditions which were attributed to a poisoning effect of the mercury. The results of a few typical experiments in this connection are shown in Fig. 1. It will be seen that concordant potential values could not be secured with any group of three electrodes unless the mercury contact was eliminated (Fig. 1, D). After rather exhaustive tests with 18 electrodes, prepared in the above manner, it was found that as many as 12 electrodes in one soil suspension agreed to within 2 millivolts, and when distributed into as many as six duplicate samples of a given soil, they agreed to within 3 or 4 mv. The potentials were usually constant and in substantial agreement within 15 minutes after insertion of the electrodes.

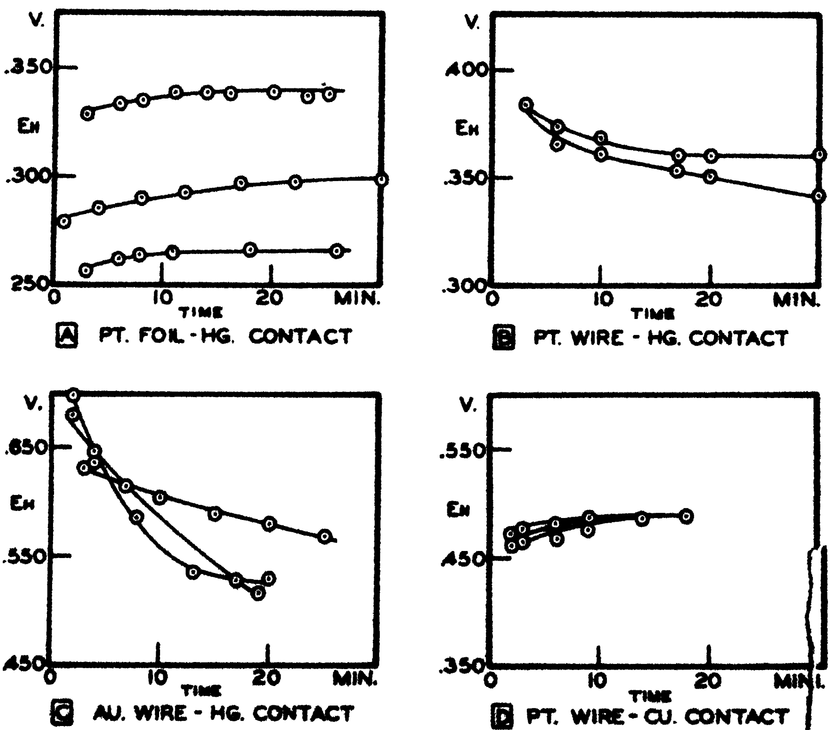

FIG. 1.—Reproducibility of metal electrodes for Eh measurement.

Another factor of importance is the time of standing before the measurement is made. Investigators have found it difficult to obtain reproducible results in soil suspensions because the potentials tended to drift over wide limits. Peech and Batjer (16) and Bradfield and co-workers (3) avoid this drift by suspending the soil in 0.1 N sulfuric acid solution which they claim serves to poise the system more effectively. In alkaline calcareous soils such treatment is not desirable, since the acid brings substances into solution which affect the potential. Volk (20) found an average difference of over 200 mv. between the potentials of soil: water suspensions and the same soils suspended in sulfuric acid.

Other workers have recommended allowing the suspensions to stand for varying lengths of time before making the Eh measurements. Darnell and Eisenmenger (7) recommended shaking the sample for 2½ to 3 days, while Peech and Batjer (16) allowed their syspension to stand for 24 hours. Brown (5) suggests centrifuging the suspensions with the platinum electrodes in place. Experiments in the present investigation showed that the latter procedure slowed up the attainment of equilibrium unless the electrodes were placed in the soil paste at the bottom of the tube.

It is also evident that when organic matter is added to a soil, the reducing conditions thus imposed will cause the Eh value to decrease, and it becomes important to know the time interval within which the value remains constant. An experiment was therefore carried out with 1:5 water suspensions of an arid and a humid soil, both with and without organic matter (alfalfa), in which the potentials were observed over an extended period of time (24 hours).

The curves so obtained, which are typical of numerous experiments of this kind, are shown in Fig. 2. It is found that where organic matter had not been added, the potential remained constant throughout the period of measurement. When alfalfa was added to the samples, however, the potential remained constant

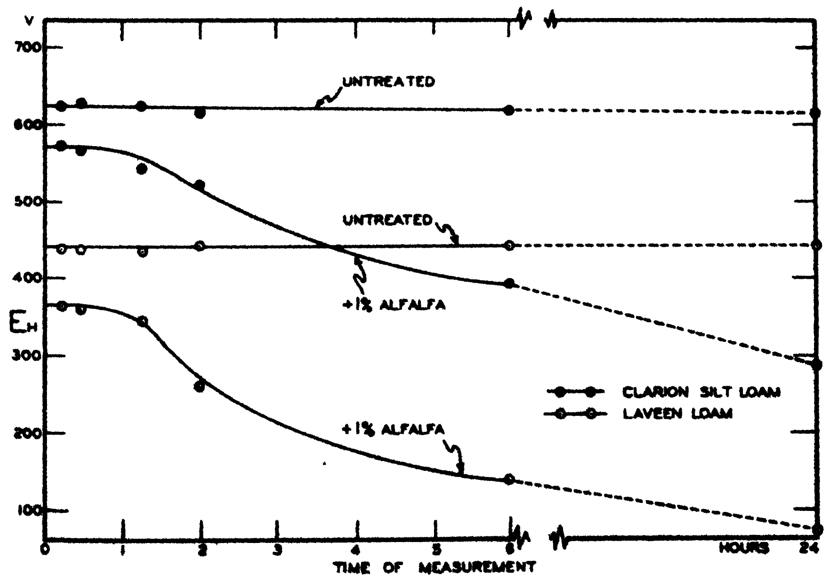

Fig. 2.—Change in Eh of Clarion silt loam and Laveen loam during period of measurement, both in presence and absence of alfalfa.

for only 20 to 30 minutes, thereafter decreasing sharply with the time. In all subsequent studies the readings were therefore taken within 30 minutes after preparation of the suspensions. Some investigators (5, 20) have considered it necessary to remove oxygen from the soil suspensions before making the Eh measurements because, as shown in a subsequent section, depletion of the oxygen by an active soil microflora when in contact with the medium for long periods of time leads to a drop in the potential. Inasmuch as equilibrium was reached in our experiments before an appreciable change in redox potential occurred, even in the presence of fresh alfalfa, removal of the oxygen present with nitrogen was unnecessary.

It might be mentioned at this point that the authors were unable to secure reproducible results on soils at field moisture contents by the procedure of Burrows and Cordon (6). This difficulty may have been due to imperfect contact of the electrodes with the sample; it was eliminated by the use of water suspensions of the soils after they had been incubated at an optimum moisture content.

PROCEDURE FINALLY ADOPTED

Suspensions of the soil in a ratio of 1 part of soil to 5 of water were allowed to come to a constant temperature of 30° C in the water bath. Before the electrodes were placed in the suspension, they were rinsed with water, heated to redness in a Bunsen flame, rinsed again, and inserted in the suspension bottle. The samples were shaken and the potentials measured at 5-minute intervals over a period of 20 to 30 minutes. The observed values were calculated to the normal hydrogen electrode taken as zero and to a constant reference pH value of 7.0.

EH-PH RELATIONSHIPS IN SOILS

Since the redox potential is a function of the pH value of the soil, it is necessary to convert observed Eh values to the same pH value in order to make the data comparable for different soils. Before such a conversion can be made, it is obviously necessary to find the proportionality factor between these two quantities. Willis (22), Heintze (8), Bradfield and associates (3), and others have shown for a wide variety of soils that when Eh values are plotted against pH values, a straight line of negative slope is obtained. This result is consistent with the thermodynamic equation for the redox potential of known organic systems as derived by Hewitt (9) and Michaelis (13).

In studying the Eh:pH relationship, it has, as previously mentioned, been customary for investigators (3, 16, 19), to change the pH of the soil by adding different amounts of acid and base before measuring the redox potentials. It has been assumed that these additions do not change the true Eh of the system. However, the acid may bring iron and other inorganic oxidizing agents into solution and seriously affect the potential. Since the organic (humus) constituents of the soil are slightly soluble in acids and therefore also extensively soluble in alkalies, such treatment may change the ratio of oxidant to reductant present in solution. Since the arid soils which constitute the basis of the present study were nearly all calcareous and high in iron, the method of acid-base addition was found to be unsatisfactory.

The results of such studies made by various investigators are shown in Table 1 and Fig. 3. In some instances the curves deviate strongly

TABLE 1.—*Comparison of Eh : pH ratios for different soils as found by different investigators.**

Designation of curve in Fig. 3	Soil	dEh/dpH	Investigators
	Acid-Base Addition Method		
A	Clarion silt loam	−0.076	Buehrer, Martin, and Parks
B	Sassafras silt loam	−0.066	Buehrer, Martin, and Parks
C	Palos Verdes gravelly sandy loam	−0.076	Buehrer, Martin, and Parks
D	Pima loam	−0.083	Buehrer, Martin, and Parks
E	Average of 5 Palestine soils	−0.053	Puri and Sarap (17)
F	North Carolina peat	−0.067	Willis (22)
G	Well oxidized New York soil	−0.100	Bradfield, Batjer and Oskamp (3)
H	Reduced soil, high in organic matter	−0.093	Bradfield, Batjer and Oskamp (3)
QH	Equi-molal mixture of quinone and hydroquinone	−0.059	Michaelis (13)
	Sandy soils from Massachusetts	−0.054	Darnell and Eisenmenger (7)
	Colloid from Ohio soils	−0.059	Kohnke (10)
	Well-oxidized silt loam subsoil from New York	−0.066	Peech and Batjer (16)
	Slightly reduced silt loam subsoil from New York	−0.063	Peech and Batjer (16)
	Average of several English soils	−0.060	Heintze (8)
	Amity clay loam from Oregon	−0.080	Stephenson, Schuster and Spulnik (18)
	Average of 132 Alabama soils	−0.067	Volk (20)
	Dilution Method		
	Tucson loam	−0.068	Buehrer, Martin, and Parks
	Mohave clay loam	−0.068	Buehrer, Martin, and Parks
	Pima loam	−0.069	Buehrer, Martin, and Parks
	Pima silty clay loam	−0.066	Buehrer, Martin, and Parks

*In Table 1 and Fig. 3 the data recorded for other investigators have been taken from published papers and are subject to the errors inherent in the process of obtaining slopes from the small published graphs

from linearity; nor are the slopes of the lines equal. Their average value is found to be about −0.075, which is considerably greater than the theoretical value, −0.060. This difficulty was obviated by taking advantage of the fact, pointed out by Baver (2) and by McGeorge (12), that when an alkaline soil is continuously diluted, the pH value increases, attaining a limiting value at a soil:water ratio of 1:10 and thereafter remaining constant. At dilutions ranging from 1:½ to 1:25, the pH values of such soils may increase by as much as 1.5 units. This phenomenon makes it possible to secure a pH change in the soil

by simple, spontaneous hydrolysis without disturbing the Eh value of the soil, except insofar as it may be influenced by the pH change itself.

The results so obtained are shown in Fig. 3 in which the soil:water ratios were varied from 1:1 to 1:25. The curves, almost without exception, are strictly linear, and the slope is found to have an average value of –0.068. This value approaches close to the theoretical –0.060 slope for some of the common organic oxidation-reduction systems such as the quinone-hydroquinone (13), succinate-fumarate (9), and lactate-pyruvate (9) systems, the latter two being common in carbohydrate decomposition.

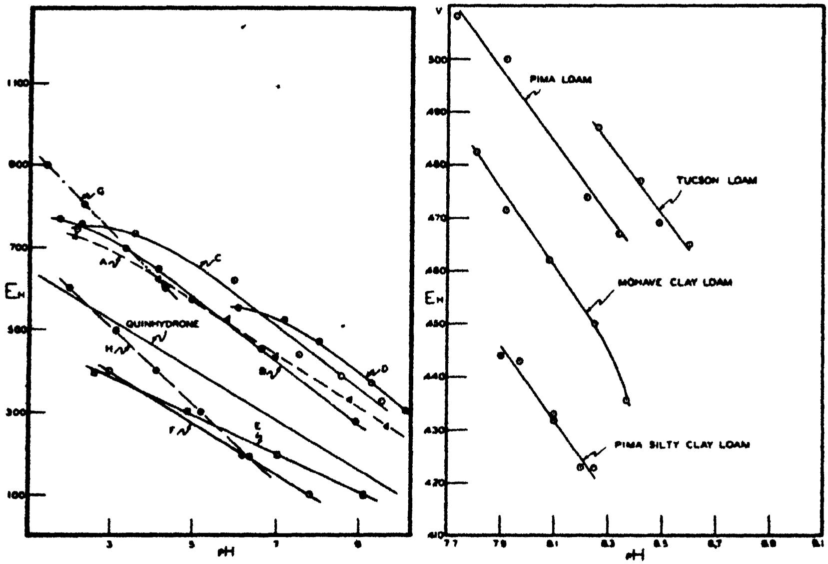

FIG. 3.—*Left*, variation of Eh with pH by acid-base addition; *right*, variation of Eh with pH by dilution method.

A comparison of the slope values obtained by the two methods is shown in Table 1. It will be seen that those in which the slope was determined by the acid-base addition method were principally humid soils, about half of which gave values averaging close to the theoretical value. The remainder, which included two desert soils, namely, Pima loam and Palos Verdes sandy loam, gave slopes considerably greater, i.e., of the order of –0.080. The group of four desert soils studied by the dilution method gave closely concordant values averaging –0.068. The latter value was accordingly employed in calculating the Eh values to the chosen reference pH value of 7.0.

INCUBATION STUDIES

For the incubation studies two soils were used: Mohave clay loam, a typical arid soil, and Clarion silt loam, a humid soil from Iowa. Part of the samples were treated with alfalfa; part left untreated. Part of the samples were kept continuously in the puddled condition

throughout the period of incubation; others were left unpuddled. All combinations and permutations were tried, and the experiment was carried out in duplicate.

The samples were placed in large petri dishes, 7½ inches in diameter and ¾ inch deep, maintained at the optimum field moisture content, and incubated at 30° C. They were puddled and repuddled daily by working with a spatula. Vertical sections of the soil were taken periodically with a large cork borer and diluted 1:5 for the redox potential measurements The pH determinations were made on a separate portion of each suspension with the Beckman pH meter.

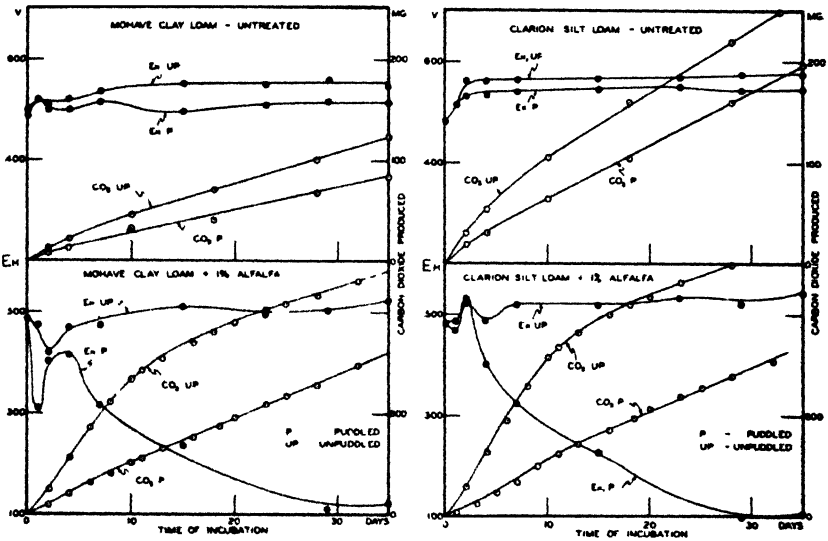

FIG. 4.—*Left*, variation of Eh of Mohave clay loam with time of incubation; *right*, variation of Eh of Clarion silt loam with time of incubation.

By way of correlation with the Eh data, the rate of decomposition of the alfalfa was observed by measuring the carbon dioxide evolved. Sixteen samples similar to those above were prepared in 500-cc Erlenmeyer flasks They were kept moist and a portion of them puddled daily, but the flasks were stoppered during the incubations. Daily carbon dioxide determinations were made by absorption in barium hydroxide according to the customary procedure.

The results are shown in Fig. 4 for Mohave clay loam and Clarion silt loam. The curves in these two figures are strikingly similar. The carbon dioxide evolution curves show that puddling of the soils decreased the rate at which alfalfa underwent decomposition to the end products of carbon dioxide and water. Even in the untreated samples, which contained less than 1% of organic matter, puddling decreased the rate.

Reflecting the differences in decomposition rate as indicated by carbon dioxide evolution, puddling also has a marked influence upon

the Eh value of the soil. In the untreated samples after 10 days' incubation, puddling resulted in an Eh value some 40 to 50 mv. lower than for the same soils under normal conditions. When alfalfa was present puddling caused an extremely large drop in potential, amounting in 30 days to approximately 400 mv.

A striking feature of these curves is the marked initial drop in potential in all cases where alfalfa was present, whether the samples were puddled or unpuddled. This drop was followed by a sharp increase which tapered off to a limiting value. In the case of the puddled soils, there was a similar sharp increase following the initial drop, but instead of attaining a constant limiting value, the Eh again *decreased* to a final limiting value. Comparing this behavior with that of the carbon dioxidê evolution curves, we note the complete absence of such a lag phase during the initial stages of the decomposition process. This phenomenon cannot be attributed to changes in microbial activity in the samples. Another possible explanation suggests itself, however. It has been observed that when an inert electrode is immersed in a sugar solution, such as sucrose or glucose, the electrode potential falls. This effect is thought by Hewitt (9) to be due to some unknown oxidation-reduction system present in the sugar solution. Perhaps a negative potential is assumed by the soil while the water-soluble carbohydrates are still present in appreciable amounts, but since they are promptly utilized by the micro-organisms, the potential may rise and assume a value characteristic of the less soluble but readily available fractions, such as the hemicelluloses and celluloses.

A similar effect was observed in another experiment illustrated in Fig. 5 in which the samples were incubated under normal, that is, unpuddled, conditions. Here again a marked drop in the potential was observed, the difference in the minimal Eh values between the untreated soil and the same soil treated with 1% alfalfa was as high as 150 mv. This phenomenon has also been observed by Darnell and Eisenmenger (7) who attributed the difference to oxygen depletion. In the present case the writers do not believe the effect to be due to the oxygen potential but rather to peculiar characteristics of the metabolic products of alfalfa, since both the treated and untreated samples had been suspended in distilled water from the same source and the potential determined before any appreciable change in the partial pressure of oxygen could have taken place.

OXYGEN POTENTIAL

It was considered of interest at this point to determine whether or not the assumption of an oxygen potential as entering into the measurement of the redox potential of a soil was justifiable. Untreated samples of Pima loam were suspended in water and redox potential measurements made at periodic intervals. The dissolved oxygen present was removed from the suspensions by aspirating with nitrogen. The results are shown in Fig. 6A. It should be emphasized that no organic matter had been added to this sample.

It appears that the oxygen potential must enter in some way into the redox potential, since the value of the latter in a nitrogen atmosphere dropped about 300 mv. in less than 10 hours' time. No change

in potential occurred in the suspension through which no gas was passed indicating that bacterial action was probably so slow that the

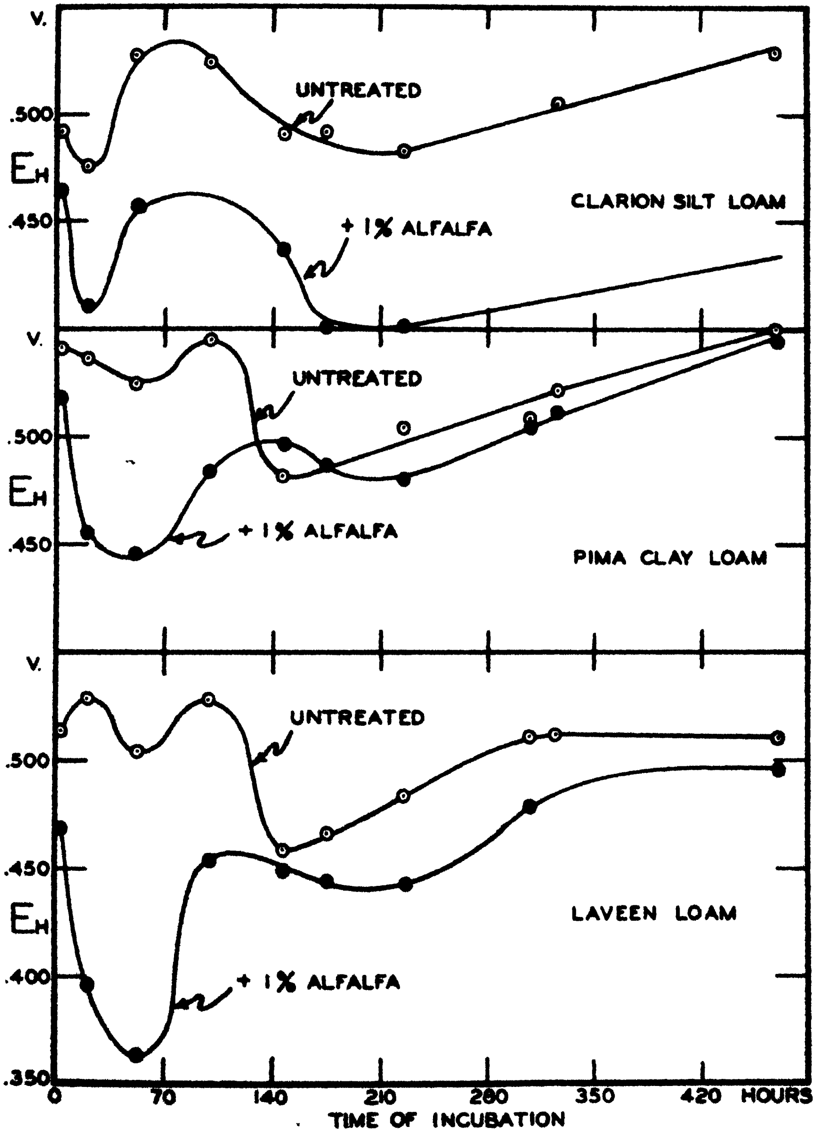

Fig. 5.—Change in Eh of normal (unpuddled) soils, with time of incubation, both in presence and absence of alfalfa.

bacteria were incapable of utilizing the oxygen faster than it could diffuse in from the atmosphere, or of accumulating sufficient reduced products under the water-logged conditions to lower the potential.

On the other hand, when oxygen was passed through the suspension, a marked rise in the potential resulted.

An experiment similar to the preceding was carried out, but in this case alfalfa had recently been incorporated with the soil and

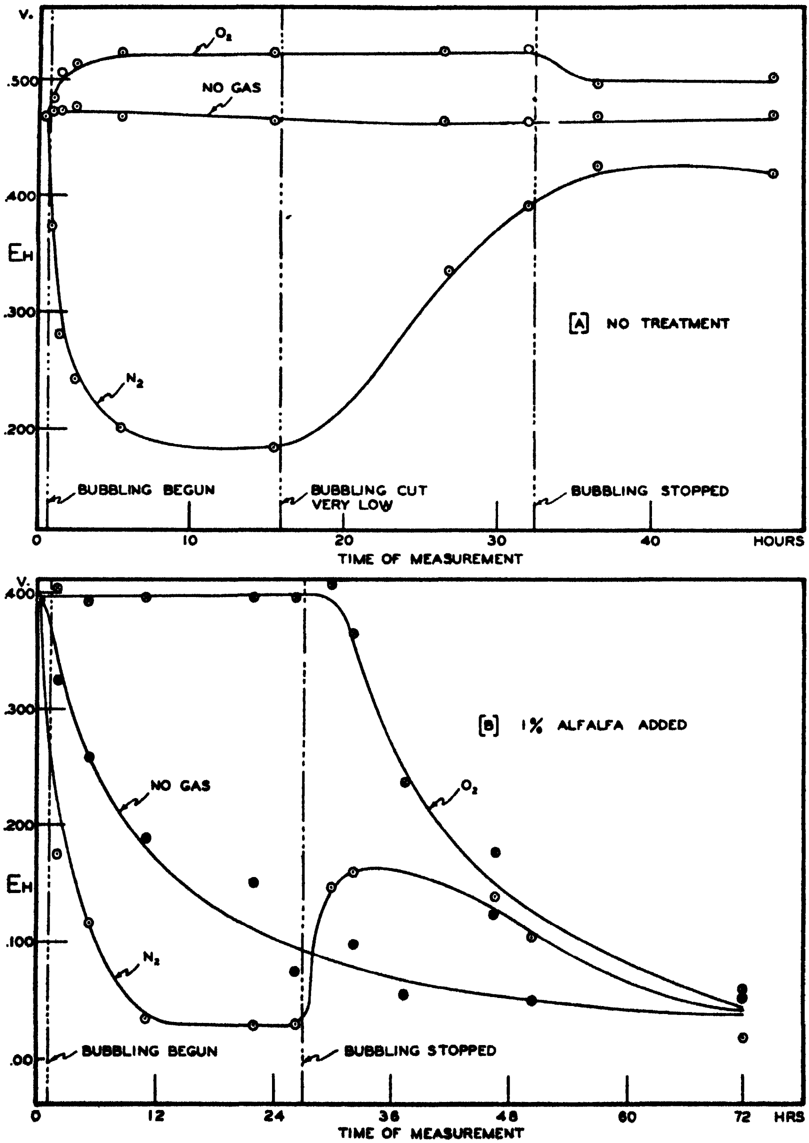

FIG. 6.—Variation of Eh of Pima loam, with time of measurement, in an atmosphere of air, nitrogen, and oxygen, respectively. A, no treatment; B, 1% alfalfa added.

allowed to decompose partially before preparation of the water suspensions. The results are plotted in Fig. 6B. It will be observed that an immediate sharp drop in potential occurred in both the sample through which no gas was passed and the one treated with nitrogen. In the case where oxygen was bubbled through, the potential remained constant until the bubbling was stopped, and thereafter it dropped sharply. It will also be noted that the Eh value of all three samples eventually became substantially constant and equal to approximately 50 mv.

This behavior may be accounted for in two ways, *viz.*, (1) the drop in potential may be due to a depletion of oxygen from the medium, either as a hydrogen acceptor in the decomposition process or by having been swept out of the suspension by the carbon dioxide produced in the decomposition; or (2) it may be due to the accumulation of reduced compounds from either reversible or irreversible oxidation-reduction systems. In this case the oxygen passing through the suspension prevents a drop in the potential by maintaining aerobic conditions.

That the latter explanation holds in part for puddled soils which are anaerobic in their environment is indicated by the fact that wide differences in potential existed between these soils and those in the unpuddled state, even though both were suspended in distilled water with identical amounts of oxygen present and measured before any appreciable change could occur. Since an identical amount of oxygen was present in each case, the differences must be attributed to some cause other than oxygen depletion.

SUMMARY

1. A study has been made of the redox potentials of arid alkaline soils with respect to organic matter decomposition, puddling, and Eh-pH relationships.

2. It was found that the Eh-pH relationship in such soils could be more satisfactorily studied by making use of the pH change due to simple dilution with water than by adding acid or alkaline solutions. The slope of the line for such soils is found to be −0 068, which approximates closely to the theoretical value for the organic systems commonly present during carbohydrate decomposition.

3. Puddling causes a marked decrease in the redox potential, particularly when the soil has been treated with alfalfa. It is believed that factors other than oxygen depletion are responsible for this decrease.

4. A sharp initial drop in the potential occurs in both puddled and unpuddled soils that have been treated with alfalfa. This effect may be attributed principally to the nature of the reduced compounds formed during the decomposition.

5. Measurements of redox potential made in an atmosphere of nitrogen and oxygen, respectively, give evidence of the existence of an oxygen potential, inasmuch as the redox potential drops sharply when nitrogen is bubbled through and increases in the presence of oxygen.

LITERATURE CITED

1. BATJER, L. P. Seasonal variation in oxidation-reduction potential of some orchard soils. Proc. Amer. Hort. Soc., 30:98–101. 1933.
2. BAVER, L. D. Factors affecting the hydrogen-ion concentration of soils. Soil Sci., 23:399–414. 1927.
3. BRADFIELD, R., BATJER, L. P., and OSKAMP, J. Soils in relation to fruit growing in New York. IV. Significance of the oxidation-reduction potentials in evalulating soils for orchard purposes. Cornell Univ. Agr. Exp. Sta. Bul. 592. 1934.
4. BREAZEALE, J. F., and MCGEORGE, W. T. Studies on soil structure: Some nitrogen transformations in puddled soils. Ariz. Agr. Exp. Sta. Tech. Bul. 69. 1937.
5. BROWN, L. A. Oxidation-reduction potentials in soils. I. Principles and electrometric determination. Soil Sci., 37:65–76. 1934.
6. BURROWS, W., and CORDON, T. C. The influence of the decomposition of organic matter on the oxidation reduction potential of soils. Soil Sci., 42:1–10. 1936.
7. DARNELL, M. C., and EISENMENGER, W. S. Oxidation-reduction potentials of soil suspensions in relation to acidity and nitrification. Jour. Agr. Res., 53:73–80. 1936.
8. HEINTZE, S. G. Soil oxidation-reduction potentials and pH values. Soil Res., 4:351–355. 1935.
9. HEWITT, L. F. Oxidation-reduction potentials in bacteria and biochemistry. 4th Ed. London County Council. London. 1936.
10. KOHNKE, H. E. L. Some factors affecting the oxidation-reduction potentials of soils. Ph.D. dissertation, Ohio State University. 1935.
11. MCGEORGE, W. T. Studies on soil structure: Some physical characteristics of puddled soils. Ariz. Agr. Exp. Sta. Tech. Bul. 67. 1937.
12. ————. The measurement and significance of hydroxyl ion concentration in alkaline calcareous soils. Ariz. Agr. Exp. Sta. Bul. 57. 1935.
13. MICHAELIS, L. Oxidation-reduction potentials. Philadelphia: L. B. Lippincott Co. 1930.
14. OBERHOLZER, P. C. J. The decomposition of organic matter in relation to soil fertility in arid and semi-arid regions. Soil Sci., 42:359–378. 1936.
15. PEARSALL, W. H. The soil complex in relation to plant communities. I. Oxidation-reduction potentials in soils. Jour. Ecol., 26:180–193. 1938.
16. PEECH, M., and BATJER, L. P. A critical study of the methods of measuring oxidation-reduction potentials of soils. Cornell Univ. Agr. Exp. Sta. Bul. 625. 1935.
17. PURI, A. N., and SARAP, A. Oxidation-reduction potentials in soils. Soil Sci., 46: 323–331. 1938.
18. STEPHENSON, R. E., SCHUSTER, C. E., and SPULNIK, J. Oxidation-reduction potentials in orchard soils. Jour. Amer. Soc. Agron., 30:91–96. 1938.
19. STURGIS, M. B. Changes in the oxidation-reduction equilibrium in soils as related to the physical properties of the soil and the growth of rice. La. Agr. Exp. Sta. Bul. 271. 1936.
20. VOLK, N. J. The determination of redox potentials of soils. Jour. Amer. Soc. Agron., 31:344–351. 1939.
21. ————. The oxidation-reduction potentials of Alabama soils as affected by soil type, soil moisture, cultivation, and vegetation. Jour. Amer. Soc. Agron., 31:577–590. 1939.
22. WILLIS, L. G. Oxidation-reduction potentials and the hydrogen ion concentration of the soil. Jour. Agr. Res., 45:571–576. 1932.
23. ————. Evidences of the significance of oxidation-reduction equilibrium in soil fertility problems. Proc. Soil Sci. Soc. Amer., 1:291–297. 1937.

THE RELATION BETWEEN SOIL REACTION, EROSION, AND AGGREGATION OF SILT AND CLAY IN CLARKSVILLE LOAM[1]

H. T. ROGERS[2]

WHILE studying the effect of soil reaction on the growth and composition of annual flowers, Shear (16)[3] observed that the more acid plats of Clarksville loam were undergoing severe erosion. Fig. 1 shows the eroded condition of one of the most acid plats.

The role of calcium in the formation of water-stable aggregates in the soil is controversial. Bradfield (4, 5) found that the coagulating value of a colloidal clay varied widely with slight changes in H-ion concentration. Reporting on the relation of exchangeable cations to the physical properties of soils, Baver (1) concluded that H-saturated soils were always less flocculated than the original untreated soil and that hydrogen flocculated the coarser particles but had a peptizing effect on the colloidal material.

More recently these investigators have pointed out some of the limitations of calcium in producing a desirable soil structure. Baver (2) stated that factors other than Ca-ion saturation are dominant in causing stable aggregation and Bradfield (6) pointed out that the formation of water-stable aggregates is much more than flocculation of colloids.

Greenhouse and laboratory investigations by Peele (12, 13), Lutz (9), and Browning (7) show that calcium in itself plays a minor role in improving the structure of heavy-textured soils. Metzger and Hide (10) found that liming improved the aggregation of a silt loam soil which had an original pH of 5.7 when followed by a growth of sweet clover or red clover but had no beneficial effect on the aggregation of unleached fallow soil in the greenhouse. It is generally conceded that an interaction of factors may be responsible for the flocculation, granulation, and aggregation of soil colloids.

DESCRIPTION OF AREA AND PLAT TREATMENTS

The five 1/40-acre plats of Clarksville loam used in this study were remarkably uniform in texture and had an original pH of 5.3. The 5 to 7 inches of yellowish-gray loam surface soil were underlain by a brownish-yellow, friable clay loam. Elevation readings showed the micro-relief of the area to be very uniform with 8.7% slope to the southeast. The treatments of the plats selected and the resulting pH, along with the textural composition of the surface soil are shown in Table 1.

Ground limestone and $Al_2(SO_4)_3$ were applied at the indicated rates to the surface of these plats. They were plowed several times during the summer of 1933 and subjected to clean cultivation of annual flowers for the next three years. Small grain cover crops were seeded in the fall of 1933 and again in 1935. A rye

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[3]Figures in parenthesis refer to "Literature Cited", p. 922.

cover crop which was grown during the winter of 1935-36 was cut and raked off the following spring. During 1937 and 1938 the plats were left to volunteer weeds and grasses.

As can be seen in Fig. 1 the more acid plats supported a poorer growth of vegetation. Seven of the 13 varieties of flowers grown obtained their average maximum growth at a soil reaction between pH 7.0 and 7.5, according to Shear (16). The other six varieties made their best growth at a pH between 5.5 and 7.0.

TABLE 1.—*Treatment, texture of soil, resulting pH, and extent of erosion of plats.*

Plat No.	Treatment (1933), lbs. per acre	Texture of soil, %			pH (1938)	Degree of erosion
		Sand	Silt	Clay		
1	6,120 lbs. $Al_2(SO_4)_3$	38.6	41.9	19.3	4.46	Severe sheet erosion and incipient gullying
2	1,933 lbs. $Al_2(SO_4)_3$	40.6	39.2	20.2	4.78	Moderate sheet erosion with rills evident after intense rains
3	None	36.4	45.1	18.5	5.32	Slight sheet erosion
4	11,680 lbs. ground limestone	34.1	46.6	19.3	7.26	Very little sheet erosion and plot well stabilized for cultivated land of this slope
5	1,933 lbs. $Al_2(SO_4)_3$ and 40,000 lbs. ground limestone	40.2	42.5	17.3	7.41	Not appreciably different from plat No. 4

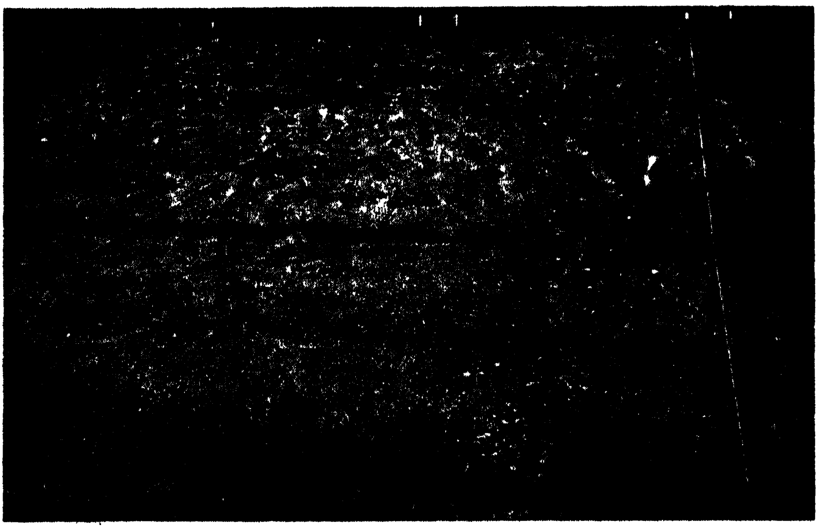

FIG. 1.—Severe erosion on acid plats of Clarksville loam, Blacksburg, Virginia.

PROPERTIES OF SOIL INVESTIGATED AND METHODS EMPLOYED

In order to determine whether the relationship observed in the field between soil reaction and extent of erosion could be attributed, in part at least, to certain physical properties of the soil which have been recognized as factors influencing erodibility, the state of aggregation of the surface soil on the different plats was investigated by a combination of wet-sieving and hydrometer methods of analysis. Thirty-five soil samples were taken during the period of June, August, and November, 1938, with a 3-inch core sampler (Fig. 2) and air dried for aggregate analysis studies. A modification of the wet screening method developed by Yoder (18) was employed to determine the distribution of coarse aggregates> 0 1 mm in size. The factor "degree of aggregation" was calculated from hydrometer analyses of the silt and clay content of completely dispersed and undisturbed soil samples. A procedure was used for the hydrometer aggregate analysis in which a 50-gram sample of soil was permitted to slake through a 5-mm sieve in a shallow pan of water before transferring to the hydrometer jar. Except for this technic the procedure varied only in some of its details from the method suggested by Bouyoucos (3) and gave close checks on duplicate samples. A glass electrode pH meter was used to determine the H-ion concentration of these samples. Organic matter was calculated from total carbon determinations which were made with a Fleming combustion furnace using ascarite absorbent. "Soluble" aluminum values were taken from a curve (Fig. 4) based on data presented by Shear (16). He secured the data from surface soil samples of this experimental area, using Morgan's (11) sodium acetate extracting solution.

FIG. 2.—Soil sampling apparatus for aggregation studies.

DISCUSSION OF RESULTS

DEGREE OF AGGREGATION AND H-ION CONCENTRATION

Field observations of the behavior of these plats showed increasing sheet erosion as the acidity increased, irrespective of $Al_2(SO_4)_3$ or other treatment (Table 1). These ratings as to extent of erosion which had occurred were made at the end of the five-year period. It was apparent after the first year that some of the plats were undergoing severe sheet erosion which continued at an accelerated rate as the experiment progressed. The amount of plant growth on the different plats naturally affected their susceptibility to erosion. The influence of this factor on either extent of erosion or soil aggregation was lessened by the plats being in rows of clean-cultivated annual

flowers rather than a close-growing crop during the season when most of the erosion occurred. Removal of the 1935–36 cover crop reduced any effect of this crop on the organic matter content of the various

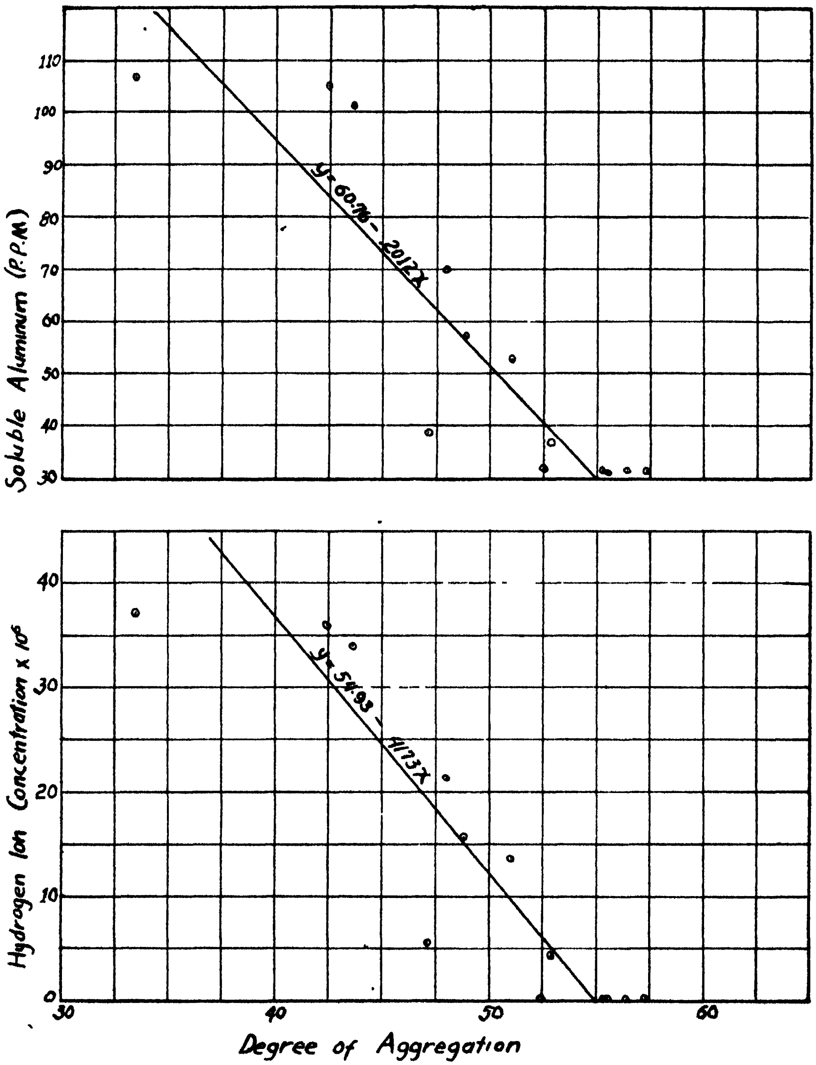

FIG. 3.—Relation of degree of aggregation to H-ion concentration and to soluble aluminum.

plats. The factor, degree of aggregation, which was used by Lutz (8) should be a good indication of the state of dispersion of the silt and clay particles in a soil. Degree of aggregation shows that fraction of

the total silt and clay in the soil when dispersed which is combined into units greater than silt size when the soil has its natural structure.

A highly significant negative correlation was found between aggregation and H-ion concentration as shown by the data in Tables 2, 3, and 4. While the percentage hydrogen saturation of the cation exchange capacity would be a good basis for studying the effect of hydrogen on the aggregation of a soil, a good correlation would be expected between percentage hydrogen saturation and H-ion concentration (15). It follows that about the same relationship would exist between percentage hydrogen saturation and degree of aggregation as was found between H-ion concentration (as measured by pH) and aggregation. Both degree of aggregation and percentage aggregates >0.1 mm in size were closely related to soil reaction. A correlation coefficient of $-.895 \pm .0576$ was found between degree of aggregation and H-ion concentration. The dispersion of the data from the regression line is illustrated in Fig. 3 where the average values for each sampling date are plotted. Distribution of the coarser aggregates, as determined by screening under water, is shown in Table 2.

TABLE 2.—*Distribution of aggregates in Clarksville loam at various acidity levels.*

Size of particle, mm	pH				
	4.46	4.78	5.32	7.26	7.41
Coarse Units (Wet Sieving), %					
2.0–5.0	3.9	4.7	6.0	3.9	6.0
1.0–2.0	3.9	4.4	5.9	4.7	6.0
0.5–1.0	5.6	5.8	6.5	6.4	6.6
0.25–0.5	7.9	9.0	10.1	10.8	12.0
0.1–0.25	15.8	16.6	16.3	18.6	19.5
Total >0.1	37.1	40.6	44.3	44.4	50.0
Small Units (Aggregate Hydrometer), %					
Total <0.05	36.3	30.1	31.2	28.9	26.9
Total <0.01	4.9	7.8	8.5	7.2	7.5
Total <0.005	1.5	3.0	4.3	3.4	3.6

TABLE 3.—*Degree of aggregation compared with H-ion concentration, soluble aluminum, and organic matter.**

Plat No.	Degree of aggregation, %†	Soil reaction		Soluble aluminum, p.p.m.	Organic matter, %
		H-ion concentration x 10^6	pH		
1	40.8	35.200	4.46	103.6	1.49
2	49.2	16.670	4.78	59.6	1.29
3	50.9	4.800	5.32	37.2	1.88
4	56.1	0.055	7.26	31.3	1.64
5	55.1	0.039	7.41	31.5	1.76

*These data are weighted averages of analyses of samples taken in June, August, and November, 1938.

†Percentage of the total silt and clay in aggregates >0.05 mm.

TABLE 4.—*The degree of association between aggregation of particles and certain related properties of Clarksville loam.*

Factors correlated	Correlation coefficient (r)	Number of cases
Degree of aggregation and H-ion concentration.....	$-0.895^{*} \pm 0.0576^{\dagger}$	13‡
Degree of aggregation and soluble aluminum......	-0.887 ± 0.0638	13‡
Degree of aggregation and percentage organic matter	0.360 ± 0.1492	35
Percentage aggregates >0.1 mm and H-ion concentration	-0.853 ± 0.0786	13‡

*Corrected for small number of cases, when less than 30, by the formula $r^2 = 1-(1-r^2)\frac{N-1}{N-2}$.

†Standard error.

‡An average of the analyses of the several samples on each sampling date constituted a case A total of 35 samples were analyzed.

A highly significant negative relationship existed between percentage aggregates >0.1 mm in size and H-ion concentration (correlation coefficient value of $-.853 \pm .0786$).

Any direct effect of the $Al_2(SO_4)_3$ treatment on the state of dispersion of the silt and clay is not evident since the check plat with no treatment and one plat with only limestone added showed the same linear relationship between soil reaction and state of aggregation as was found in the other plats.

DEGREE OF AGGREGATION AND SOLUBLE ALUMINUM

It is highly probable that the properties of Ca-ion saturation and soil reaction have only secondary influences and some other factor or combination of factors is dominantly responsible for the development of a soil structure which would be resistant to the eroding action of water. Recognizing the heterogeneity of soils in their natural state, it is only reasonable to conclude that the formation of stable aggregates in various soils under field conditions is a very complex process. The close association found between degree of acidity and the state of dispersion of the silt and clay in this soil suggests that some property closely associated with soil reaction might be a dominant factor in producing water-stable aggregates. Sideri (17) studying clay-humus formations states, "The elimination of iron and aluminum oxides from the surface of clay particles increases the ability of these particles to aggregate." He believed that the presence of large amounts of these oxides destroyed the orienting properties of clay with respect to humus, resulting in mere coagulation. Whether the quantities of aluminum brought into solution at the acidity of these soils would be sufficient to have an appreciable effect on aggregate formation is not known. However, there is no particular reason to assume that the quantity of aluminum (30 to 100 p.p.m.) removed by a sodium acetate extraction is all of that fraction which might affect the formation of aggregates. The curve showing the relation between acidity and soluble aluminum in Fig. 4 is in accordance with the relationship between these properties reported by Pettinger (14). He showed that large quantities of aluminum come into solution below pH 4.8 and above pH 7.5 with a critical point on the curve above neutrality at about pH 8.5.

The relation between soluble aluminum and aggregation of silt and clay is shown to be high by the correlation coefficient of $-.883 \pm .0638$. This value is not significantly different from the coefficient ($-.895 \pm$

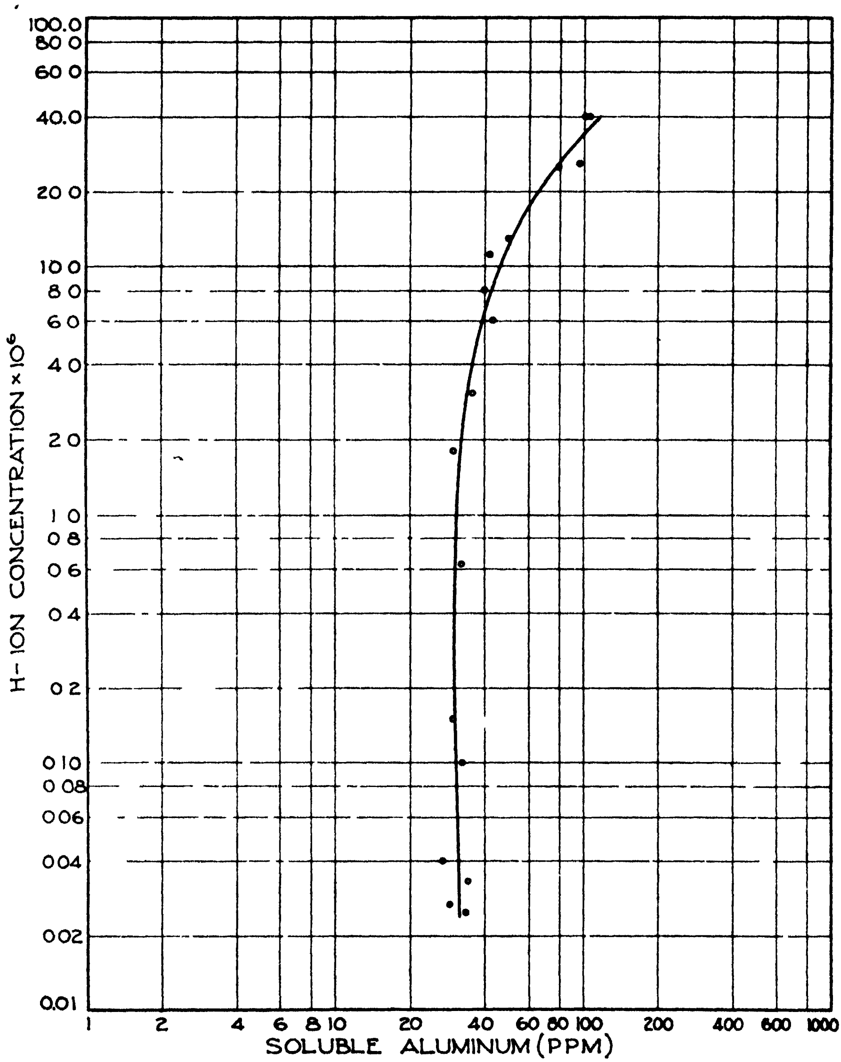

FIG. 4.—Relation of H-ion concentration to soluble aluminum. This graph was adapted from published (16) and unpublished data by G. M. Shear.

.0576) expressing the relationship between degree of aggregation and H-ion concentration. The highest pH obtained in this study (7.41) was not sufficiently alkaline to bring large quantities of aluminum into solution above neutrality.

DEGREE OF AGGREGATION AND ORGANIC MATTER

The value of organic matter in improving soil structure has been stressed by many workers and unquestionably the physical condition of some soils is greatly benefited by the addition of organic materials. In the case of this Clarksville loam soil, however, there was no significant relation between total organic matter and the extent of aggregation. This does not preclude the possibility of a relation between the humus content and aggregate formation.

SUMMARY

In a series of plats of Clarksville loam, ranging in pH from 4.45 to 7.41, a close correlation was observed between erodibility and soil reaction. These field observations were substantiated by a laboratory study of the soil. A highly significant negative correlation was found between degree of aggregation and H-ion concentration. Two entirely different procedures were employed for measuring the aggregate condition of the soil and both methods showed this relationship to exist between extent of aggregation and soil reaction.

Increasing quantities of soluble aluminum were accompanied by decreasing quantities of silt and clay aggregated into units larger than silt size. No significant relationship existed between total organic matter and degree of aggregation or observed erodibility.

The addition of ground limestone to Clarksville loam up to the quantity required to produce a neutral reaction definitely improved the physical condition of the soil and its resistance to erosion.

LITERATURE CITED

1. BAVER, L. D. The relation of exchangeable cations to the physical properties of soils. Jour. Amer. Soc. Agron., 20:921–941. 1928.
2. ———. Aggregation of soils and calcium ion saturation. Amer. Soil Survey Assoc. Bul., 16:28–30. 1936.
3. BOUYOUCOS, G. J. The ultimate natural structure of soils. Soil Sci., 28:27–37. 1929.
4. BRADFIELD, R. The relation of H-ion concentration to the flocculation of a colloidal clay. Jour. Amer. Chem. Soc., 45:1243. 1923.
5. ———. Factors affecting the coagulation of colloidal clay. Jour. Phy. Chem., 32:202. 1928.
6. ———. The value and limitations of calcium in soil structure. Amer. Soil Survey Assoc. Bul., 16:31–32. 1936.
7. BROWNING, G. M. Changes in the erodibility of soils brought about by the application of organic matter. Soil Sci. Soc. Amer. Proc., 2:85–96. 1937.
8. LUTZ, J. F. The physico-chemical properties of soils affecting soil erosion. Mo. Agr. Exp. Sta. Res. Bul. 212. 1934.
9. ———. The relation of the calcium and H-ions to some physico-chemical properties of clays. Amer. Soil Survey Assoc. Bul., 16:24–27. 1936.
10. METZGER, W. H., and Hide, J. C. Effect of certain crops and soil treatments on soil aggregation and the distribution of organic carbon in relation to aggregate size. Jour. Amer. Soc. Agron., 30:833–843. 1938.
11. MORGAN, M. P. The universal soil testing system. Conn. Agr. Exp. Sta. Bul. 372. 1935.
12. PEELE, T. C. The effect of calcium on the erodibility of soils. Soil Sci. Soc. Amer. Proc., 1:47–51. 1936.
13. ———. The effect of lime and organic matter on the erodibility of Cecil clay. Soil Sci. Soc. Amer. Proc., 2:79–84. 1937.

14. PETTINGER, N. A. A useful chart for teaching the relation of soil reaction to the availability of plant nutrients to crops. Va. Agr. Ext. Div. Bul. 136. 1935.
15. ROGERS, H. T. Some physico-chemical relationships found in four erosive soils of the Piedmont Plateau Region. Jour. Amer. Soc. Agron., 29:1–9. 1937.
16. SHEAR, G. M. The effects of soil reaction on the growth and chemical compositon of annual garden flowers. Va. Agr. Exp. Sta. Tech. Bul. 63. 1938.
17. SIDERI, D. I. On the formation of soil structure: IV. The structure of mixed clay-sand and clay-humus formations. Soil Sci., 46:129–137. 1938.
18. YODER, R. E. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. Jour. Amer. Soc. Agron., 28:337–351. 1936.

LINKAGE RELATIONS BETWEEN SMUT RESISTANCE AND SEMISTERILITY IN MAIZE[1]

CHAS. R. BURNHAM AND J. L. CARTLEDGE[2]

EARLIER studies by Immer (18)[3] and Hoover (17) on the inheritance of smut resistance in maize made use of certain genetic markers to test for possible linkages. In many cases the associations found were with characters of a morphological type which might conceivably offer extremely favorable conditions for smut infection as, for example, brachytic, liguleless, tassel seed, and ramosa.

In order to study the factors which normally differentiate smut resistant from smut susceptible strains of maize, the present work, using chromosomal interchanges as genetic markers, was undertaken. Interchanges in heterozygous condition appear to bring about no change in morphology other than the abortion of about 50% of both ovules and pollen. The physiological conditions in such semisterile plants may differ from those in the normal plants, but it was hoped that this would not be sufficient to give false evidence of linkage.

MATERIAL

Three smut-resistant lines were available, derived, one each, from the Reid Yellow Dent, Boone County White, and Lancaster Surecrop varieties inbred at the West Virginia Experiment Station for 12 to 14 generations. For most of the work the Lancaster Surecrop line was used since it was most resistant, only one smutted plant having been found since it was first isolated. In a few cases the Boone County White and the Reid Yellow Dent resistant lines were used also. For the susceptible strain a Leaming line inbred over the same length of time was selected, since it was highly susceptible to infection in all portions of the plant.

For the chromosome markers, a series of interchanges was selected from those available from Anderson's study of x-ray induced interchanges (1), and those which had occurred naturally (4, 6, 7). Several were selected involving each chromosome, wherever possible with breaks so located that linkage might be detected under ordinary conditions over the entire length of the chromosome. A list of the interchanges used, together with available information on the positions

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[2]Formerly Associate Geneticist at the West Virginia Agricultural Experiment Station and Agent of the U. S. Dept. of Agriculture, Division of Cereal Crops and Diseases, and Assistant Professor of Genetics, West Virginia Agricultural Experiment Station, respectively.

We wish to express our appreciation to Dr. R. J. Garber for crosses involving his long-time inbred smut reaction lines and certain of the chromosomal interchanges and for his continued interest as the study progressed and to C. T. Thorniley for most of the pollen classification. We wish to thank Dr. E. G. Anderson not only for furnishing us with the greater part of the interchanges used, but also for supplying his unpublished cytogenetic data which appear in Table 1 of this publication. The senior author wishes to acknowledge that the final analysis of the data and his part in the preparation of this paper were completed at the Minnesota Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 933.

of the breaks in the chromosomes and in the linkage maps is given in Table 1. A cytological locus listed as 0.7 in the long arm means that the break is at a locus 0.7 of the distance from the spindle fiber to the end of the long arm. We are indebted to Dr. E. G. Anderson for furnishing the unpublished data on his interchanges indicated in the table.

TABLE 1.—*List of chromosomal interchanges used, together with cytogenetic data on the positions of the breaks.*

Interchange	Positions of breaks in chromosomes		Data source	Positions of break loci (T) in corresponding genetic maps		Data source
1–2a	1L.7[1]	2L.6	(13)	f T-3-an	lg v-13-T	(5)
‡1–2c	1S.7	2L.3	†	T-sr P	—	†
‡1–6a	1L.13	6L.43	(6,13)	T-13-br f	Y Pl-8-T	(6)
‡1–9b	1L.6	9L.5	(2)	br ±7	c wx-38-T	(2)
1–9c	1S.6	9L.2	(2)	near P	c wx-13-T	(2)
1–10a	1L.4	—	†	near br	T-15-g R	†
*2–3a	2S.9	3L.6	(13)	lg <1	na-10-T-21-a	(13)
2–4c	—	4S	(13)[2]	v-T-Ch	near su	†
*2-4d	—	4L	(13)[2]	B-18-T-6-v	close to Tu	†
‡2–6a	2L.4	6S.0+	(13)	lg B-30-T	Y-2-T-6-Pl	(13)
*3–5a	—	—	—	close to na	T-40-bm-pr	(13)
3–5c	—	—	—	na-12-T-13-a	near pr	†
*3–7b	—	—	—	d ±0.4	near ra	†
‡3–8a	3L.6	8L.8	(3)	na-T-ts	T-7-ms j	(3)
3–8b	3L.1	8L.2	(3)	—	T-33-ms j	(3)
*3–10a	3L.1	10L.1	†	ts ±10	T-15-g R	†
4–5c	4S	—	(13)[2]	near su	bm-16-T-3-pr	(†, 13)
4–5d	4S	—	(13)[2]	near su	near bm	(†, 13)
*4–9a	4L.1	9L.8	(2)	su ±(2 or 21)	c wx-(12 or 31)-T	(2)
5–7a	5L.8	7L.7	(11)	bm pr-15-T-14-v	ra ij-11-T	(11)
5–7b	5L.2	7S.4	(13)	bm-7-T pr	T-11-ra gl	(13)
5–9a	5L.7	9S.0+	(12)	pr-22-T-6-v	c wx-<1-T	(12)
‡6–8a	6L.5	8L.7	(3)	near Pl	T-8-ms j	(3)
6–10a	6L.7	10L.1	†	Pl sm-22-T	T-10-g R	†
8–9a	8L.2	9L.4	(10)	T-28-ms j	sh wx-14-T	(10)
9–10a	9L.3	10L.9	†	c wx-4-T	g R-5-T	†

[1]Chromosome 1, break in long arm 0.7 of distance from spindle fiber to end of that arm.
[2]Based on cytogenetic data on 4–5a and 4–5b.
†Anderson's unpublished data.
‡Highly significant odds.
*Significant but lower odds.

In Fig. 1 is a summary of the loci on the cytological map. In several instances where only genetic data were available, estimates of the loci have been made based on combined cytogenetic information from other interchanges which were not used in these smut studies, and consequently are not listed. The cytological loci are expected to be accurate only within limits. More accurate placing of the loci requires extensive study of each to determine the frequency of variation in the position of the cross-shaped synaptic figure in heterozygous individuals (10). Detailed study of certain of them had been completed but was not undertaken for each of the others for this smut study.

METHODS

The chromosomal interchange lines were expected to be relatively susceptible since they were from unselected material. The previous work of Hoover (17) had indicated that under the conditions at this station resistance was at least partially

dominant. Accordingly, for the linkage tests the interchanges were crossed with smut-resistant lines and in several cases also with the susceptible Leaming line. Both F_1's were backcrossed to the same susceptible Leaming line. These backcross progenies segregate semisterile plants (heterozygous for the interchange) and normal plants (not carrying the interchange) in a 1:1 ratio; and where the parents differed in smut reaction should also segregate for smut resistance.

In order to study further the behavior of resistance in crosses, progenies from selfing the interchange×resistant F_1, and from backcrossing it to the resistant line were grown.

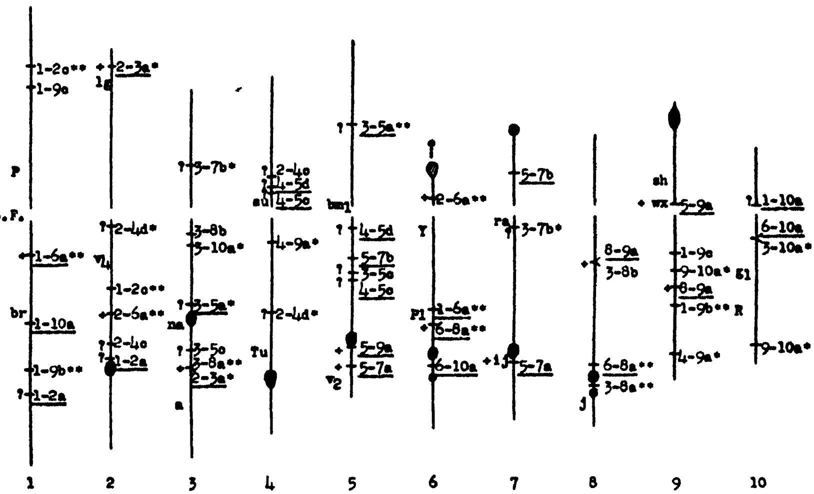

FIG. 1.—Chromosome map of maize showing the loci of interchanges used in the smut study. Those underlined were tested in backcrosses to susceptible of both the (interchange×resistant) F_1 and the (interchange×susceptible) F_1. All the others were tested in backcrosses of only the (interchange× resistant) F_1.

Key to symbols: + opposite a locus means good cytological and genetic data; ? opposite a locus means meager cytologic evidence or only genetic data; none opposite a locus means incompletely summarized cytologic and genetic data; ** gave odds of 99:1 or better indicating linkage between smut reaction and the interchange; * gave low but significant odds indicating linkage.

To give a more uniform opportunity for smut infection, smut spores from boils collected from all parts of smutted plants the previous season were mixed with rotted manure and the mixture allowed to stand in piles for four to five days before spreading between the corn rows. At least three applications of this mixture were made at 10-day intervals after the plants were about 18 inches high. The susceptible and resistant checks were repeated at regular intervals in the field and in the 1938 trial, where possible, single rows of each backcross were replicated and scattered at random in the test plat.

Every fifth plant was tagged and numbered in the field. At the pollen-shedding stage, a tassel branch from each plant was collected and preserved for later pollen sterility classification. Later in the season smut records on each plant were taken, final ear smut notes being taken when the plants were completely matured.

A significant difference in the percentage of smutted plants in the normal and semisterile classes is an indication of linkage between either or both interchange points and a gene or genes for smut reaction. In the progeny of the F_1 (interchange ×resistant) backcrossed to susceptible, such a linkage would result in a higher percentage of smutted plants in the semisterile class than in the normal class, since the original interchange parent was susceptible. Final analysis was made by using Fisher's X^2 test of association for a 2×2 classification involving two different character pairs, the simplified formula being:

$$X^2 = \frac{(ad-bc)^2 N}{(a+b)\ (c+d)\ (a+c)\ (b+d)},$$

entering the X^2 table with one degree of freedom (15). Corrections were made for discontinuity only for those cases in which the P values were near the borderline of significance, or where the numbers were small (16).

RESULTS

In Table 2 is a general summary showing the results from different kinds of crosses and the reaction of the resistant and susceptible parental lines. The same interchanges were not involved in the entire series of crosses, but data from a series involving the same interchanges show relatively the same results. The F_1 of susceptible Leaming×resistant Lancaster was not grown nor were adequate data on the interchange parents obtained. The 1936 results for the different crosses are considered first. The F_1 of susceptible interchange× resistant Lancaster is slightly less resistant than the resistant line itself, with 2.40% of smutted plants as compared with 0%.

TABLE 2.—*Percentages of smut observed in resistant and susceptible inbred lines and in F_1, F_2, and backcrosses involving chromosomal interchange lines, smut plat, West Virginia Experiment Station, 1936, 1937, and 1938.*

Lines	1936		1937		1938	
	Total population	% smut	Total population	% smut	Total population	% smut
Interchange×Leaming susc. F_1	449	36.75	—	—	—	—
Interchange×Lancaster Res. F_1	466	2.40	816	1.96	—	—
Interchange×Boone Co. Res. F_1	138	5.07	—	—	—	—
Interchange×Reid Res. F_1	61	8.20	—	—	—	—
(Interchange×Res.)×Res	255	3.92	—	—	—	—
(Interchange×Res.) selfed	345	2.90	607	3.79	188	4.79
(Interchange×Res.)×Leam. Susc.	3,078	19.98	5,348	24.93	6,123	24.15
(Interchange×Susc.)×Leam. Susc.	1,017	47.69	—	—	—	—
Leaming Susc. Check	865	37.20	275	50.55	249	54.22
Lancaster Surecrop Res.	64	0.00	142	0.00	79	0.00
Boone County White Res.	74	0.00	123	1.63	81	1.23

This F_1 when backcrossed to the resistant parent showed 3.92% of smutted plants; when backcrossed to the susceptible parent the progeny contained 19.98% of smutted plants. The F_1 of interchange× susceptible Leaming was as susceptible as the susceptible Leaming parent, 36.75% as compared with 37.20%. From the above results

it may be concluded that smut resistance in the Lancaster resistant line is at least partially dominant and that under the conditions at this station the backcross to the susceptible parent is the better one to use for a study of segregation for smut reaction factors.

Data were obtained in 1936, 1937, and 1938 from backcrosses to the susceptible parent, a summary being given in Table 3. Backcrosses in which there was some evidence of linkage in the first tests were repeated the next year along with new backcrosses. In Table 3 are given the numbers of smutted and normal plants, the percentages of smutted plants in the semisterile and in the normal classes, the total population for each, and the X^2 and P values for the tests of association between semisterility and smut reaction. It will be noted in Table 2 that a high percentage of the plants in the susceptible check escaped infection and that the percentage of smutted plants in this line was much higher in 1937 and in 1938 than in 1936. Values of P that are 0.05 or smaller are usually accepted as indicating significant deviations from a random distribution, 0.05 corresponding to odds of 19:1. The following interchanges, double starred on the map in Fig. 1, had P values corresponding to odds equal to or greater than 99:1, the deviations being in the direction expected from linkage with smut resistance: 1–2c, 1–6a, 1–9b, 2–6a, 3–8a, and 6–8a. The others that had significant but low odds, single starred in Fig. 1, were 2–3a (23:1 odds); 2–4d (24:1); 3–5a (63:1); 3–7b (29:1); 3–10a (24:1); 4–9a (21:1); and 9–10a (66:1).

Since an interchange involves an exchange of pieces between two non-homologous chromosomes, the linkage obtained is in each case evidence for the location of smut reaction factors in either or both chromosomes, that is, near either or both loci at which the original interchange breaks occurred. To determine which of these three possibilities is true a test must be made for each of the two loci with an additional interchange involving a break at nearly the same locus in one of the chromosomes, the other break in this additional interchange being in a third or different chromosome This latter break locus may need to be checked in the same manner with still another interchange. For example, there is some evidence (odds 24:1) that 3–10a is linked with smut susceptibility. The locus of the 3–10a break in chromosome 3 is checked in a similar linkage test of a 3–8b interchange whose break in 3 is near that of 3–10a in 3. The 3–10a break in 10 is checked similarly by data from a 6–10a interchange whose break in 10 is near that of 3–10a in 10. The locus of 3–8b in 8 and the locus of 6–10a in 6 may then need to be checked by still other interchanges. Since the original interchange stocks might also be carrying factors for smut resistance, one method of study is to cross each interchange with both the resistant Lancaster and the susceptible Leaming lines; backcrossing both F_1's to the susceptible Leaming line. Negative evidence for association from only the F_1 of interchange×resistant does not eliminate the possibility that the interchange line was carrying the same smut resistance factor or factors in its interchanged chromosomes as was the inbred resistant line in its normal homologues. For only 13 of the interchanges are both kinds of backcross tests available, underlined in Fig. 1. In those backcrosses

TABLE 3.—*Summary of data on the progeny from the (interchange × Lancaster resistant) F_1 when backcrossed to the Leaming susceptible line, grown in the smut plat, West Virginia Experiment Station, 1936, 1937, and 1938.*

F_1 cross	Year tested	Normal		Semisterile		Total population	Normal class % smutted	Semi-sterile class % smutted	X^2	P
		Smutted	Not smutted	Smutted	Not smutted					
1–2a × Res.	'36	57	215	55	198	525	19.91	20.44	0.048	.80
1–2c × Res.	'37, '38	53	261	91	257	662	16.88	26.15	8.334	<.01‡
1–6a × Res.	'36, '37, '38	143	625	238	639	1,645	18.62	27.14	16.694	<.01‡
1–9b × Res.	'37, '38	148	377	193	311	1,029	28.19	38.29	11.846	<.01‡
1–9c × L. S. Res	8	10	38	17	34	99	20.83	33.33	1.948	.2
1–10a × Res.	6, 8	68	216	75	279	638	23.94	21.19	0.689	.3
2–3a × Res.	6, 7, 8	133	699	147	585	1,564	15.99	20.08	4.172[1]	.04*
2–4c × L. S. Res	8	15	43	11	33	102	25.86	25.00	0.010	.9
2–4d × Res.	7, 8	88	265	117	247	717	24.93	32.14	4.221[1]	.04*
2–6a × Res.	6, 8	55	228	96	184	563	19.43	34.29	15.816	<.01‡
3–5a × Res	6, 7, 8	45	149	75	142	411	23.20	34.56	5.863[1]	.016*
3–5c × L. S. Res.	7, 8	58	309	78	289	734	15.80	21.25	3.258[1]	.07
3–7b × Res.	7, 8	51	167	44	83	345	23.39	34.65	4.543[1]	.03*
3–8a × Res.	7, 8	210	602	250	488	1,550	25.86	33.88	11.895	<.01‡
3–10a × Res	7, 8	87	321	124	325	857	21.32	27.62	4.229[1]	.04*
4–5c × L. S. Res	6	18	77	27	110	232	18.95	19.71	0.021	.9
4–5d × L. S. Res.	6	2	22	2	19	45	8.33	9.52	0.020	.9
(4–5d × L.S. Res.)(×)	7	3	210	5	196	414	14.08	24.88	0.636	.5
4–9a × Res.	7, 8	66	237	88	213	604	21.78	29.24	4.033[1]	.045*
5–7a × L. S. Res.	6	12	83	17	84	196	12.63	16.83	0.685	.5
5–7b × L. S. Res.	8	14	51	6	51	122	21.54	10.53	2.687	.1
5–9a × Res.	6, 8	39	118	32	96	285	24.84	25.00	0.001	.98
6–8a × Res.	6, 7, 8	46	393	108	322	869	10.48	25.12	31.922	<.01‡
6–10a × Res.	6, 8	27	157	22	149	355	14.67	12.87	0.244	.7
8–9a × L. S. Res.	6	10	67	12	50	139	12.99	19.35	1.045	.3
9–10a × L. S. Res.	8	2	70	7	32	111	2.78	17.95	5.911[1]	.015*

[1]Corrected for discontinuity on the total populations.
‡Highly significant odds.
*Significant but lower odds.

using the F_1 of (interchange × susceptible) the populations were small, although there was a high incidence of smutted plants. Although none of the 13 interchanges gave any indication of carrying a factor for resistance which was linked with the interchange, it cannot be concluded that this applies to all interchanges in these studies. Unfortunately both kinds of backcrosses were not tested for all the interchanges used.

An analysis of the results follows, considering the interchanges for which the odds indicate probable linkage and in each case the negative results which have a bearing on the conclusions.

For interchange 1–2c the odds are greater than 99:1. Since T1–9c, whose locus in chromosome 1 is near that of 1–2c, shows negative results, the locus of T1–2c in chromosome 2 is probably the one responsible for the linkage, although the population for T1–9c was small.

Interchange 1–6a also had odds greater than 99:1. Its locus in 1 was not checked, but its locus in 6 is near that of 6–8a which also showed high odds. Hence the locus of 1–6a in 6 and possibly in 1 may be responsible for the linkage.

Interchange 1–9b had odds greater than 99:1. Its locus in 9 is near that of 8–9a for which there was no evidence of linkage in both kinds of backcrosses. Had these been based on adequate numbers, they would indicate the locus of 1–9b in 1 is responsible for the linkage. The locus of 1–2a in 1 is given in Fig. 1 as being near that of 1–9b, but it is not placed there with certainty. Hence the negative results with 1–2a may not conflict with this conclusion.

Interchange 2–3a showed odds of only 24:1. Its locus in 2 was not checked while its locus in 3 is near that of T3–8a for which there was evidence of linkage. If the linkage exists, either that in 3 or both loci in T2–3a may be associated with smut reaction.

For interchange 2–6a the odds were greater than 99:1. Its locus in 2 is near that of 1–2c for which the evidence is positive. It is also near those of both 2–4c and 1–2a in 2, both of which showed negative evidence, although their loci in 2 are not certainly placed. This region in 2 probably contains smut reaction factors. The locus of 2–6a in 6 was not checked. Hence this locus in 6 may or may not be involved also in the linkage.

For interchange 3–8a association was indicated by high odds. Its locus in 3 is near that of 2–3a which also had positive evidence of linkage and also is near that of 3–5c which showed negative evidence but is not certainly placed. The locus of 3–8a in 8 is near that of 6–8a for which there was also good evidence of linkage. Therefore, either or both loci in 3–8a may be responsible for the linkage.

Interchange 3–10a had low odds for association. Its locus in 3 was checked by 3–8b and its locus in 10 by 6–10a both of which gave negative evidence but are based on small populations. If the linkage with 3–10a exists, one possible explanation is that either 3–8b or 6–10a carries the same smut resistance factor as does the resistant line and hence would have shown the linkage only in the backcrossed interchange × susceptible F_1 which was not tested.

For interchange 6–8a there were high odds. Each locus is near that of a second interchange which also had high odds indicating linkage. Since no locus in either of these was eliminated, either or both loci in 6–8a may be associated with smut reaction.

For interchange 9–10a the odds were significant, but the evidence is based on a small population. If the linkage exists, the locus in chromosome 10 must be involved since its locus in 9 is near that of 8–9a for which the results were negative.

For 2–4d (24:1 odds), 3–5a (63:1), 3–7b (29:1), and 4–9a (21:1) none of the break loci was checked for linkage with smut resistance with another interchange. For the first three interchanges, however, the loci are not placed with certainty. If linkage exists, either or both loci may be involved if their positions in Fig. 1 are approximately correct.

Eight of the interchanges that showed negative results in the progeny from backcrossing the F_1 of (interchange×resistant) also showed negative results in backcrosses of the F_1 of (interchange×susceptible). These double tests indicate regions in chromosomes 1, 2, 4, 6, 7, 8, 9, and 10 and a considerable part of the long arm of 5 which do not carry smut reaction factors (Fig. 1) differentiating the resistant and susceptible lines used in these studies.

DISCUSSION

In several cases, a locus that appears to be relatively close on the map to a locus not showing linkage, may be too far away to show linkage with smut reaction. The reasons for this will be apparent from what follows. Evidence on genetic length and corresponding cytologic length is available for the short arm of chromosome 9. Cytogenetic evidence indicates the gene waxy is in the short arm (12) probably near the spindle fiber. The genetic length from the terminal knob to waxy corresponding to most of the short arm is 53.5 units according to the Cornell linkage summary (14). Although this cytogenetic length may not be applicable directly to the other chromosomes, it gives an indication of what physical length may correspond to about 50 units.

The genetic length which a given interchange will test for the presence of smut reaction factors depends on (a) the degree of reduction in crossing over in the presence of the interchange in heterozygous condition and (b) the relative amounts of smut shown in the different homozygous and heterozygous genotypes for the different smut factors. In the susceptible Leaming inbred line, which with its long period of inbreeding should have been relatively homozygous for smut reaction factors, an average of more than 50% of the plants escaped infection. In a segregating progeny these cannot be distinguished from genotypically resistant plants. The evidence from the linkage tests indicates that several factors must be concerned in smut resistance. If these were all of equal value in their reaction to infection, a case of close linkage should give a greater difference, spoken of below as "relative difference", between the percentages of smutted plants in the semisterile and in the normal classes, than should a case of loose linkage. This would be modified if several pairs of smut fac-

tors were involved and if they were unequal in smut reaction value; that is, if comparable genotypes for different pairs of alleles differ in their reaction to smut infection. In this case, the "relative differences" in percentages of smut for interchanges involving different chromosomes would depend on the particular smut reaction alleles involved as well as the strength of linkage. In the data presented here the "relative differences" in percentages of smutted plants vary from 4 to 15 with different interchanges.

Immer (18) obtained positive evidence for the association of smut reaction with the pericarp factor *P*. The trials in the present paper involve different material and therefore not necessarily the same factors for smut reaction. They do not eliminate the possibility that in this material also there may be a smut reaction factor in the region near the locus of 1–6a in 1.

In addition to linkages that might be termed "morphological associations", Hoover (17) obtained linkage between smut reaction and su, v_2, sh wx in crosses with certain inbred lines and not with other inbred lines; the inbred lines differing as to the region of the plant in which most of the smut boils were located. This problem of the factors involved in the localization of smut boils is one which needs further study.

USES OF INTERCHANGES AND INVERSIONS AS GENETIC TOOLS

In this smut study, the interchanges were crossed with each of two pure lines which differed in smut reaction, one resistant, the other susceptible. Without previous information on inheritance, semisterile F_1 plants in each of these crosses would then be backcrossed to each of the two smut reaction lines for a study of segregation of smut reaction in relation to semisterility. A more satisfactory method would have been to make the genetic backgrounds of all the interchanges being used more comparable by backcrossing each F_1 to the original inbred smut reaction line for 5 or 6 generations.

Inversions which give considerable sterility in the pollen when heterozygous may be used in the same manner as the interchanges and may be even more useful since each would test the presence of factors on only one chromosome.

In addition to their use for genetic studies of a problem such as disease resistance, interchanges, and inversions should be useful additional tools for genetic studies of earliness and many quantitative characters.

If the partial sterility affects ears and pollen, the study of a character such as yield is complicated by the fact that such plants do not yield as much grain as do normal sibs. Preliminary data indicate that although half the grains are missing on a semisterile ear, the yield of shelled corn is not decreased proportionately. Weights and kernel counts taken on a series of paired normal and semisterile plants show that on the semisterile ears the grains are significantly heavier than the grains on comparable normal ears.

SUMMARY

Crosses between susceptible chromosomal interchange lines and a resistant Lancaster Surecrop inbred line were backcrossed to a sucseptible Leaming inbred to study segregation for smut reaction in relation to the interchange points.

Highly significant deviations (odds 99:1 or greater) from randomness were obtained, the deviations being in the direction expected with linkage between smut resistance and the following interchanges: 1–2c, 1–6a, 1–9b, 2–6a, 3–8a, and 6–8a. Less significant deviations (odds not less than 19:1) but in the same direction were obtained for 2–3a, 2–4d, 3–5a, 3–7b, 3–10a, 4–9a, and 9–10a.

Of these interchanges, incomplete evidence indicates the locus of 1–2c in chromosome 2 is one of the loci showing linkage with smut reaction. In all other cases, the break locus in either, or the loci in both chromosomes involved in the interchanges listed above may be associated with smut resistance.

The method of procedure in the use of interchanges and inversions for this and other multiple factor problems has been considered.

LITERATURE CITED

1. ANDERSON, E. G. Chromosomal interchanges in maize. Genetics, 20:70–83. 1935
2. ———. Translocations in maize involving chromosome 9. Genetics, 23:307–313. 1938.
3. ———. Translocations in maize involving chromosome 8. Genetics, 24:385–390. 1939.
4. BRINK, R. A. The occurrence of semi-sterility in maize. Jour. Her., 18:266–270. 1927.
5. BRINK, R. A., and COOPER, D. C. The association of semisterile-1 in maize with two linkage groups. Genetics, 16:595–628. 1931.
6. ———, ———. A strain of maize homozygous for segmental interchanges involving both ends of the P-Br chromosome. Proc. Nat. Acad. Sci., 18:441–455. 1932.
7. BURNHAM, C. R. Genetical and cytological studies of semisterility and related phenomena in maize. Proc. Nat. Acad. Sci., 16:269–277. 1930.
8. ———. The association of non-homologous parts in a chromosomal interchange in maize. Abstr. Proc. Sixth Intern. Congress Genetics, 2:19–20. 1932.
9. ———. Linkage relations of certain factors and their serial order in chromosome 5 in maize. Abs. in Amer. Nat., 68:82. 1934.
10. ———. Cytogenetic studies of an interchange between chromosomes 8 and 9 in maize. Genetics, 19:430–447. 1934.
11. ———. Linkage relations of certain factors and their serial order in chromosome 5 in maize. Abs. in Amer. Nat., 68:82. 1934.
12. ———. Chromosomal interchanges in maize: Reduction of crossing over and association of non-homologous parts. Abs. in Amer. Nat., 68:81–82. 1934.
13. ———. Unpublished data.
14. EMERSON, R. A., BEADLE, G. W., and FRASER, A. C. A summary of linkage studies in maize. Cornell Univ. Agr. Exp. Sta. Mem. 180. 1935.
15. FISHER, R. A. Statistical Methods for Research Workers. Edinburg: Oliver and Boyd. 1936.
16. GOULDEN, C. H. Methods of Statistical Analysis. New York: John Wiley & Sons. 1939.
17. HOOVER, M. M. Inheritance studies of the reaction of selfed lines of maize to smut. (*Ustilago zeae*). W. Va. Agr. Exp. Sta. Bul. 253:1–32. 1932.
18. IMMER, F. R. The inheritance of reaction to *Ustilago Zeae* in maize. Minn. Agr. Exp. Sta. Tech. Bul. 51:1–55. 1927.

SYMBIOTIC PROMISCUITY OF TWO SPECIES OF CROTALARIA[1]

J. K. Wilson[2]

DURING the past 50 years many phases of the relationships existing between the legume bacteria and the leguminous plants have been studied. One of these which has stimulated much research because of its practical application is the degree of specificity ascribed to members of a certain genus towards strains of the Rhizobia. An illustration of this is provided by the clover plant-bacteria group in which species of trifolium only are listed. The group was established from experimental evidence which indicated that the species of the Rhizobium for this genus is specific. Similar relationships are ascribed to other genera and to specific organisms that bear definite names for these genera. Thus, the species of the bacteria for the clover group is *Rhizobium trifolii*, that for the alfalfa group, *Rh. meliloti*, and so on to the extent of the groups. With this classification, if a species or strain of the bacteria from one group should be found, for one reason or another, to associate with a species of plant from another plant-bacteria group, it might be described at one time as *Rh. trifolii* and at another time as *Rh. meliloti*, or it might bear various names, depending on the source from which it came.

Several investigators have observed that a strain of the Rhizobium from a certain plant that has been placed in a plant-bacteria group is not so specific as the group would indicate. Some workers have dismissed such data on the grounds of faulty technic, but recently Wilson (1)[3] reopened this question and reported many such irregularities. He (2) was unable to find an organism that was specific for a group of plants or for one plant. Among other things, he (1) also found that *Crotalaria verrucosa* nodulated with only 3 of 32 strains, while *C. grantiana* nodulated with 29 of the same 32 strains. These 29 strains were isolated from plants representing about 10 plant-bacteria groups and from plants that have not been placed in any group.

Wilson (1) emphasized further that several species of Crotolaria and species of other genera are more promiscuous in their relations with strains of the rhizobia than others; *Amorpha fruticosa* L., *Medicago sativa* L., *Phaseolus coccineus* L., *Robinia pseudoacacia* L., and others being promiscuous, and *Cicer arietenum* L., *Ornithopus sativus* Bort., *Psoralea onobrychis* Nutt., and many others being restricted.

Such data suggest that a single strain may be encountered in the nodules of numerous legumes irrespective of the plant-bacteria group or groups to which the legumes may have been assigned. In this connection numerous instances were reported by Wilson in which a strain from a plant appeared equally well or better adapted to other species, irrespective of the plant bacteria groups, than it was to the plant from which it was isolated. It appears, therefore, if a number of

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[2]Soil Bacteriologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 939.

strains of the rhizobia from a large number of genera or from a plant like *Amorpha fruticosa* that is promiscuous were tested in this regard, that valuable information bearing on several phases of the relationships existing between the legume bacteria and the leguminous plants may be obtained. It is the purpose of this paper, therefore, to record the symbiotic promiscuity of *Crotalaria grantiana* Harvey and *C. verrucosa* L. with 182 isolations of the rhizobia which were obtained from a wide selection of legumes and to emphasize their relations to the established plant-bacteria groups.

METHODS

The method employed in a piece of work will influence the strength of the conclusions that can be drawn. For this reason, if confidence in the results is invited, the selection of a method is highly important. In this case it should provide surroundings in which the symbionts can be housed together during the growing period to the exclusion of interfering organisms and maintain satisfactory growing conditions. Such a method was described by Wilson (1) and was followed in executing the experiments reported in this paper.

Seeds of both species of Crotalaria were planted in containers plugged with cotton and grown simultaneously so that each species was exposed to the same isolations of the Rhizobium and to the same light, heat, and variations that normally occur in a greenhouse. Because the supply of seeds of both species of Crotalaria was limited only 10 to 12 or so were planted in each container. It might have been better to have had a larger number of plants in each test for Wilson (1) pointed out that the occurrence of nodules on plantlets of *Medicago sativa* and on plantlets of other species may not be observed with a small number of plants when employing certain strains of the rhizobia but might be if a larger number of plants are grown for examination.

The cultures of the organism used represent isolations from 71 species and varieties, representing 46 genera, one of which was not identified. Each isolation was known to effect symbiosis from tests with appropriate seedlings, employing these same methods. Certain isolations may be identical, especially those from a definite source, although the isolations from *Amorpha fruticosa* are known to be extremely dissimilar in many cases (Wilson, 2). Part of the work was repeated as many as four times, a part only two or three times, and, in a few cases, individual tests were made.

DATA

The data are given in summary form in Table 1. They show that both species of Crotalaria are promiscuous in their relations with strains of the Rhizobia and that *C. grantiana* is more promiscuous than is *C. verrucosa*. The former bore nodules with 137 of the 182 isolations, while the latter bore nodules with only 41 of the same isolations. Among these isolations were 52 from *Amorpha fruticosa* L. With 42 of these *C. grantiana* bore nodules and with 17 of the 52 *C. verrucosa* bore nodules. In every case when *C. verrucosa* bore nodules with these isolations from *A. fruticosa*, *C. grantiana* also bore nodules with the corresponding isolations. In no case did *C. verrucosa* bear nodules with an isolation from *A. fruticosa* that failed to nodulate with *C. grantiana*. In some cases when both species bore nodules with the same strain one species might be strongly nodulated while the

other might be weakly nodulated. It is evident, therefore, that both species of Crotalaria are not equally suited to bear nodules with the same isolation or with isolations from an identical source.

TABLE 1.—*Summary of data, showing symbiotic promiscuity of two species of Crotalaria with isolations of Rhizobium from numerous species of legumes.*

Sources of isolations	Number of isolations	Number symbiosing with	
		C. grantiana	*C. verrucosa*
Amorpha fruticosa	52	42	18
Astragalus menziesii	3	2	0
Astragalus rubyi	4	4	1
Daubentonia drummondii	3	3	1
Lotus corniculatus	8	5	0
Lotus scoparium	2	2	0
Medicago sativa	11	7	3
Robinia pseudoacacia	4	4	0
Trifolium pratense	9	8	0
Trifolium repens	3	3	0
Vicia villosa	12	12	0
All other species	71	45	18
Total	182	137	41

Among those isolations tested on both species of Crotalaria are three from *Astragalus menziesii* A. Gray and four from *A. rubyi*. *C. grantiana* bore nodules with all isolations except one from *A. menziesii*, while *C. verrucosa* bore nodules with only one and that one was an isolation from *A. rubyi*. Also, there were three isolations from *Daubentonia drummondii* Rydb. *C. grantiana* bore nodules with each isolation, while *C. verrucosa* bore nodules with only one of them. In this case nodulation was excellent. *C. grantiana* also bore excellent nodules with this isolation. In addition, *C. grantiana* nodulated with isolations from *Lespedeza hirta* (L.) Hornem, *L. procumbens* Michx., *L. striata* Hook & Arn, and *L. violaceae* (L.) Pers., while *C. verrucosa* nodulated with isolations from the first and last species only. Further, there were eight isolations from *Lotus corniculatus* L. and two from *L. scoparium*. *C. grantiana* bore nodules with five of the eight strains and with both strains from *L. scoparium*, while *C. verrucosa* bore no nodules at all with any one of the 10 isolations.

There were 11 isolations of Rhizobium from *Medicago sativa* L. *C. grantiana* bore nodules with seven of these, while *C. verrucosa* bore nodules with only three of the 11. In no case, with either species of Crotalaria, were the plants excellently nodulated.

When nine isolations of Rhizobium from *Trifolium pratense* L. were employed, *C. grantiana* bore nodules with eight of the isolations, while *C. verrucosa* bore no nodules with the same isolations. When three isolations from *T. repens* L. were employed, *C. grantiana* bore nodules with each isolation, while *C. verrucosa* failed to nodulate with the same isolations. When the isolations from *T. incarnatum* L. and from *T. suaveolens* Willd. were employed, *C. grantiana* bore nodules but *C. verrucosa* did not. When the isolations from *T. johnstonii* and

from *T. subterraneum* were employed, neither species of Crotalaria bore nodules.

In addition, *C. grantiana* bore nodules when grown in association with other isolations, while *C. verrucosa* did not. The sources of these were *Albizzia julibrissin* Biov. (Durazinni), one of two isolations; *Amphicarpa monoica* (L.) Ell.; *Apios tuberosa* Moench; *Aspalanthus sarcodes* Vog. et Walp.; *Coronilla varia* L.; *Crotalaria spectabiles* Roth.; *Dalea alopecuroides* Willd., one of three isolations; *Indigofera viscosa* Lam., one of two isolations; *Glycine max* (L.) Meer.; *Mimosa pudica* L.; *Parosela scoparia* (A. Gray) Heller., one of three isolations; *Oxytropis lambertii* Pursh., one of two isolations; *Petalostemon purpurea* (Vent.) Rydb.; *Prosopis juliflora* DC.; *Robinia pseudoacacia*, four isolations; *Rynchosia minima* (L.) DC.; two of three isolations; *Sutherlandia frutescens* R. Br.; *Tephrosia grandiflora* Pers.; *Vicia villosa* Roth, 12 isolations; *V. atropurpuria* Desf.; *V. disperma* DC.; *V. villosa* Roth var. Gore; and an unidentified species.

Further, both species of Crotalaria bore nodules when grown in association with isolations from the following plants: *Acacia constricta* Benth.; *Albizzia julibrissin*, one of two isolations; *Crotalaria sagittalis* L.; *Cassia chamaecrista* L., one of two isolations; *Dalea alopecuroides*, two of three isolations; Desmodium canadense (L.) DC., one of two isolations; *Sesbania macrocarpa* Mahl.; *Stizolobium deeringianum* Brot.; *Sutherlandia frutescens*, one of two isolations; and *Swainsonia coronillaefolia* Salisb.

Also, both species of crotalaria failed to bear nodules when grown in association with isolations from the following plants: *Baptisia australis* R. Br.; *Caragana frutescens* DC.; *Cassia chamaecrista*, one of two isolations; *Cicer arietinum* L., two isolations; *Desmodium canadense*, one of two isolations; *Droycnium herbaceum* Vill.; *Laburnum vulgaris* Gris.; *Lens esculenta* Moench.; *Lupinus sp.*; *L. perennis* L.; *Onobrychis viciaefolia* Scop.; *Ononis vaginalis* Vahl.; *Oxytropis lambertii; Parosella scoparia*, two of three isolations; *Phaseolus vulgaris* L.; *Spartium scoparium* L.; *Strophostyles helvola* (L.) Britton; *Tephrosia virginianum* (L.) Pers.; *Thermopsis caroliniana* M.A. Curt.; and *Vigna sinensis* Endl.

It was observed also that *C. verrucosa* bore nodules when grown in association with the isolation from *Phaseolus polystachyus* (L.) B. P., while *C. grantiana* did not.

SIGNIFICANT FACTS IN THE FINDINGS

Certain significant points in the data should be emphasized. One of these relates to the placing of *C. grantiana* and *C. verrucosa* in a plant-bacteria group. If the bearing of nodules by a plant when grown in association with an isolation of the rhizobia is the criterion for placing a plant in any one of the plant-bacteria groups, then these two species can be placed in any one of several groups depending upon the particular isolation that was employed in making the tests. When employing a certain isolation both species might be placed with *Amorpha fruticosa*, when employing another isolation *C. grantiana* might be placed with *A. fruticosa* while *C. verrucosa* might not be placed with either. If still another isolation was employed, neither

species would be placed with *A. fruticosa*. It is clear, therefore, that the particular isolation will determine the placing of a plant in any group or in no group.

If this method of procedure is followed, *C. grantiana* can be placed in at least 10 of the plant-bacteria groups and *C. verrucosa* in four. If enough isolations were tested, it should be suspected that both species might be placed in still more groups. As suggested by Wilson (2) this means that a strain is not specific and that it may be found at one time in the nodules of one plant representing one plant bacteria group and at another time in the nodules of another plant representing still another group or another genus.

It should be emphasized also that *C. grantiana* is decidedly more promiscuous in its relations with the various isolations of the rhizobia than is *C. verrucosa*, for as stated above the data show that *C. grantiana* bore nodules with 137 of the 182 isolations while *C. verrucosa* bore nodules with only 41 of the same isolations. This indicates that, although plants may belong to a certain genus, there is no necessary connection between this and their relations with the various strains.

Wilson (1) pointed out in studying 19 species of Crotalaria that *C. grantiana* was the most promiscuous while *C. verrucosa* was the most restricted. The other 17 species which came between these extremes also exhibited no detectable relationship between the fact that they belong to a single genus and their relations with strains of the rhizobia which came from a definite genus or from a definite source. Wilson (3) also pointed out that this promiscuity is closely associated with the degree of cross-pollination of the species. Plants that are obligatorily cross-pollinated or depend on insects to effect pollination are the most promiscuous. If this is true then the boundaries surrounding every species must be as irregular as the mixing of characters through cross-pollination from year to year would indicate. Under these conditions the boundaries surrounding highly self-fertilizing plants are more regular than those surrounding highly cross-pollinating plants. This might indicate that *C. grantiana* is highly cross-pollinating and *C. verrucosa* highly self-pollinating, although no data are available bearing on the degree of selfing or crossing of these two species of Crotalaria.

Some emphasis should be placed on the fact that each species of Crotalaria was not equally suited to bear nodules with the same strain. If nodulation was weak on *C. grantiana* when employing a certain strain, it was absent in numerous instances on *C. verrucosa*. This was observed in 53 instances. In about 50% of the cases when nodulation was good on *C. grantiana* it was weak on *C. verrucosa*. Whether this condition is native to the species or to the bacteria is unknown. It may be due somewhat to the environmental condition under which the plantlets were grown.

DISCUSSION AND CONCLUSION

The data presented in this paper substantiate and extend those recently published by Wilson (1). In his work he employed isolations from most of the plant-bacteria groups and was unable to place

Crotalaria grantiana and *C. verrucosa*, as well as many other plants, in any group. In the present work 182 isolations were employed and were obtained from plants representative of each plant-bacteria group and from many species that have not been placed in any group or possibly from which isolations have never been made. The same type of promiscuity was observed with these 182 isolations as that which was observed by Wilson. With these conditions existing it was impossible to assign either species to a plant-bacteria group.

From the evidence presented it seems that the particular isolation employed in making the tests will determine whether a species is placed in this or that group. This is taken to mean that the plant-bacteria groups as now recognized are entirely inadequate. If one attempts to use such groups and is unable to place a species in just one group, it is difficult to come to any other conclusion. The plant-bacteria groups may have some practical value, but when the data presented here are considered in connection with those previously published, it is obvious that from the scientific standpoint the plant-bacteria groups should be abandoned.

If promiscuity between the various strains of the rhizobia and certain species of legumes is as widespread as the data show, then it is evident, as stated above, that a strain may be found at one time in the nodules of a plant from one plant-bacteria group and at another time in the nodules of a plant from a different plant-bacteria group. Therefore, at one time a strain may bear the name *Rhizobium meliloti* and at another time *Rh. trifolii*. In this connection *Crotalaria grantiana* bore nodules with organisms from 11 of the plant-bacteria groups and with organisms from 14 species of legumes that have not been included in any group. Also *C. verrucosa* bore nodules with organisms from four of the plant-bacteria groups and with organisms from eight species that have not been included in any group.

It is perfectly logical, therefore, if the proposed method of naming an organism is followed, that any strain of the rhizobia may be given different names at different times or by different workers depending upon the source from which it was obtained. This is another reason for abandoning the plant-bacteria groups. Such findings may also partly explain some of the apparent contradictions in the literature concerning the morphology and the physiology of strains from a certain species, especially species that are highly promiscuous.

LITERATURE CITED

1. Wilson, J. K. Leguminous plants and their associated organisms. Cornell Univ. Agr. Exp. Sta. Mem. 221. 1939.
2. ———. Symbiotic promiscuity in the Leguminosae. Trans. Third Com. Int. Soc. Soil Sci., A: 49–63. 1939.
3. ———. A relationship between pollination and nodulation of the Leguminosae. Jour. Amer. Soc. Agron., 31:159–170. 1939.

AVAILABILITY, FIXATION, AND LIBERATION OF POTASSIUM IN HIGH-LIME SOILS[1]

HUBERT ALLAWAY AND W. H. PIERRE[2]

MANY small areas of high-lime soils occurring in that part of Iowa covered by the Wisconsin drift have been found to produce very poor crops. Corn grown on these areas shows a marginal "firing" or dying of the leaves and is often a complete failure, whereas on the surrounding soil it normally produces over 50 bushels per acre. Although it has been found that the application of potassium fertilizers to these soils will bring about large increases in crop yields, relatively little information is available upon which to base a satisfactory explanation of these facts.

These high-lime soils occupy naturally poorly drained sites and commonly contain as much as 25% calcium and magnesium carbonate. Since the areas are relatively small, usually varying in size from a few square rods to several acres, they have not been shown in the county soil survey maps but have been included with soils of the Webster series with which they are associated.

The problem of improving the high-lime soils of Iowa was recognized in 1915 by Stevenson and Brown (18).[3] At that time these soils were called "alkali" soils and an excess of soluble salts was considered to be responsible for their low productivity.

In 1918 Bancroft (2) differentiated these high-lime soils from the arid alkali soils of Wyoming and attributed their low productivity to the high concentration of calcium carbonate and bicarbonate.

Stevenson, Brown, and Boatman (19) reported results of fertilizer experiments on high-lime soils in 1926. A profitable response to potassium fertilization was shown in several cases.

Kilpatrick (11) concluded from more recent field experiments that unproductive high-lime soils will produce as good yields as the rest of the field if they are fertilized with from 100 to 500 pounds of potassium chloride per acre. The beneficial effects of this treatment seem to disappear, however, within two or three years after the application.

Dean (7) found 12 high-lime soils from Iowa to be high in total potassium, but 11 of the 12 were low in available potassium as measured by the *Aspergillus niger* method. Four of the 11 were low and the other 7 were slightly low according to standards set up by the authors of the method.

Sears (17) attributed the low productivity of the high-lime soils of Illinois to low available potassium and unusually high nitrate content. One of these soils which responded to potassium fertilization was found to be low in exchangeable potassium. He presents some evidence that rapid fixation of added potassium may contribute to the low level of available potassium.

McGeorge (13) studies the availability of potassium in the calcareous soils of Arizona. He found that although these soils were low in water-soluble potassium, they were relatively high in exchangeable potassium and did not show immediate

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[3]Figures in parenthesis refer to "Literature Cited", p. 953.

need for potassium fertilization. From this work it is evident that the calcareous soils of Arizona differ from the soils studied by Dean and Sears.

In recent years considerable information has been published concerning the availability of the exchangeable and non-exchangeable potassium and the factors which affect the relative amounts of these forms of potassium in the soil. Several investigators (12, 21, 23) have demonstrated that fixation of potassium in a non-exchangeable form is an important factor in determining the fertility of soils. It has also been shown (1, 4, 9, 10, 16) that the non-exchangeable potassium of the soil may be liberated fast enough to make an important contribution to the supply of potassium available to plants. However, very little data of this type have been obtained for high-lime soils.

The objectives of the study reported here were (a) to determine the amounts of exchangeable potassium in unproductive high-lime soils and to determine whether or not the poor corn growth on these soils as compared to the good growth on adjacent soils can be explained on the basis of differences in exchangeable potassium; and (b) to determine whether the marked response to potassium fertilizers on unproductive high-lime soils and the relatively small residual effects from large potassium applications can be explained by a high potassium fixing power or a relatively slow liberation of potassium from the non-exchangeable to the exchangeable form.

SOILS STUDIED AND METHODS USED

In July, 1938, samples of soil were taken from high-lime spots in nine different corn fields in north central Iowa. In six of these fields demonstrations of the effect of potassium fertilizers were being carried on by the Iowa Agricultural Extension Service and marked responses to applications of potassium fertilizer were being obtained. Soil samples were taken from unfertilized areas where the corn showed marked symptoms of potassium deficiency, namely, marginal firing of the leaves and stunted growth. Samples were also taken from unfertilized areas a short distance away where the corn appeared to be growing normally. In several instances, two samples of soil were taken from the area which was supporting good crop growth, and in one case two samples of the unproductive soil were obtained. In all fields the sample from the area of normal plant growth was taken less than 100 feet away from the area on which plants showed marked symptoms of potassium deficiency. Each sample was a composite of ten borings. All samples were taken at two depths, *viz.*, 0–6 inches and 6–12 inches. In no case was there an appreciable difference in the appearance of the soil at the two depths.

The demonstrations carried on by the Extension Service furnished some general information on the yields of the unproductive spots and the response of these areas to potassium fertilization.

The exchangeable potassium was extracted by leaching 10 grams of soil with 250 cc of normal ammonium acetate. The leachate was evaporated to dryness, treated with a 6% solution of hydrogen peroxide in order to destroy the organic matter, and the ammonia driven off. Potassium was determined in an aliquot representing 2 grams of soil by the method of Brown, Robinson, and Browning (5). This method was modified to include two washings of the precipitate with 70% alcohol instead of the single washing. This method was found to extract practically all of the exchangeable potassium and to give reproducible results and satisfactory recovery of potassium from standard solutions.

Organic carbon was determined by the method of Walkley and Black (24).

Carbonate determinations were made by digesting 0.5 to 2.0 grams of soil with standard hydrochloric acid. The soil was then placed on a filter and the excess hydrochloric acid was washed out with barium chloride. The filtrate and washings were then titrated with standard sodium hydroxide, using methyl red as the indicator.

In determining the potassium-fixing power of the soil 3 cc of a standard potassium chloride solution were added to 10 grams of air-dry soil. The concentration of the solution used was such that this amount of potassium was equivalent to an application of 252 pounds per 2,000,000 pounds of soil. The samples were then placed in a saturated atmosphere for 24 hours, after which the water-soluble and exchangeable potassium were determined by the same method used for the untreated soil. The amount of potassium fixed by the soil was obtained by subtracting the amount found from the sum of the original exchangeable potassium content of the soil and the amount added.

The rate at which potassium is liberated from the non-exchangeable form was determined by exhausting the soil of exchangeable potassium and then incubating it for 80 days at 30% moisture. At the end of this time the exchangeable potassium was determined and the amount found was considered to have been liberated from the non-exchangeable form. The removal of the exchangeable potassium at the start of the experiment was accomplished by leaching the soil with normal ammonium acetate. This was followed by a leaching with calcium acetate to restore the colloid to nearly its original condition in regard to calcium saturation. The excess calcium acetate was washed out with water before incubation.

RESULTS

FIELD OBSERVATIONS AND DATA

The description of the plants at the time of sampling the soil and the yields and responses to potassium fertilization on the unproductive areas are shown in Table 1. Fig. 1 shows the appearance of the corn on the untreated and fertilized plats in the Carlson field. Since the yield data in Table 1 represent the results from only one year, and since the plats were established as demonstration rather than on an experimental basis, the data must be regarded as only approximations. However, the beneficial effect of potassium fertilization is definitely demonstrated.

EXCHANGEABLE POTASSIUM AND OTHER CHEMICAL DATA

The exchangeable potassium, calcium carbonate, and organic matter contents of the unproductive high-lime soils and the adjacent soils which supported good crop growth are shown in Table 2.

In every case it was found that the unproductive soils contained less exchangeable potassium than the soils from the same fields which supported good corn growth, the values being 31 to 743% greater in the latter. The same general relation held true for the second 6-inch layers, although in samples from the Barnes and Bennett fields the 6- to 12-inch layer of the productive soil was also quite low in exchangeable potassium. The first 6 inches of the unproductive soils contained an average of 151 pounds of exchangeable potassium per 2 million pounds of soil, whereas the productive soils averaged

396 pounds. Based on the average of the first and second 6 inches, 9 of the 10 unproductive soils contained less than 175 pounds of potassium per 2 million pounds of soil, whereas 10 of the 12 soils which were supporting normal crop growth contained more than this amount.

The unproductive soils generally contained more calcium carbonate than did the productive soils from the same field. The average amount of calcium carbonate in the top 6-inch layer of the soils on which corn

FIG. 1.—Response of corn to potassium fertilizer on high-lime soils in the Carlson Field, 1938. Fertilizer was applied along the row with fertilizer attachment to cultivator approximately six weeks after planting. (Four rows per plat.)

showed deficiency symptoms was 24.0% as compared with only 12.5% in the productive soils. In some cases there was very little difference in the calcium carbonate content of the productive and unproductive soils. Eight of the 10 soils on which the plants showed deficiency symptoms contained more than 15% calcium carbonate, whereas 8 of the 12 soils on which normal corn growth was found contained less than this amount.

The organic carbon content of all the soils was high, ranging from 4.8 to 8.8%. There was no consistent relation between organic matter content and growth of the corn.

TABLE 1.—*Location of samples, description of plants, yields, and responses to potassium fertilization.**

Soil sample No.	Description of plants at time of sampling soil, July 15–16, 1938	Yield of corn on untreated area, bu. per acre	Response to fertilization
	Patterson Field (Hamilton Co.)		
1	Marked deficiency symptoms; good response to potassium fertilization	45.4	74% from 125 lbs. of 0–20–10 per acre
2	Corn normal, about 4½ feet high, 60 feet from sample 1		
	Nolte Field (Wright Co.)		
3	Marked deficiency symptoms; good response to fertilization; corn about 1 foot high	30.7	95% from 200 lbs. KCl per acre 77% from 100 lbs. KCl per acre
4	Corn apparently normal, 4 to 5 feet high		
5	Very good corn growth; 80 feet from sample 3		
	DeWolf Field (Pocahontas Co.)		
6	Deficiency symptoms; corn 2½ feet high; good response to fertilization	42.5	42% from 200 lbs. KCl per acre 10% from 100 lbs. KCl per acre
7	Normal corn growth, about 5 feet high; 50 to 70 feet from sample 6	82.1	
8	Normal corn, about 5 feet high		
	Carlson Field (Pocahontas Co.)		
9	Marked deficiency symptoms, 1 to 2 feet high; good response to fertilization	6.7	930% from 500 lbs. KCl per acre 728% from 200 lbs. KCl per acre
10	Normal corn, 5 to 6 feet high; 20 feet from sample 9		
11	Vigorous corn growth, 6 to 6½ feet high		

	Barnes Field (Palo Alto Co.)		
12	Marked deficiency symptoms		
13	Normal corn growth, about 5 feet high		
	Conway Field (Palo Alto Co.)		
14	Deficiency symptoms; some response to fertilization	60.0	23% from 200 lbs. KCl per acre 26% from 100 lbs. KCl per acre
15	Marked deficiency symptoms; 25 to 30 feet from sample 14		
16	Normal corn, about 5 feet high; 50 feet from sample 15		
	Vaudt Field (Kossuth Co.)		
17	Marked deficiency symptoms; good response to potassium fertilization	25.0	188% from 200 lbs. KCl per acre 151% from 100 lbs. KCl per acre
18	Normal corn 5 to 6 feet high; 60 to 70 feet from sample 17		
	Bennett Field (Story Co.)		
19	Normal corn about 4 feet high; 40 to 50 feet from sample 20	63.4	
20	Marked symptoms of potassium deficiency	43.2	
	Erickson Field (Story Co.)		
21	Marked symptoms of potassium deficiency	50.6	
22	Normal corn 4 to 5 feet high; 40 to 50 feet from sample 21	54.3	

*Since plats were not replicated, yield and response data are only approximations.

TABLE 2.—*The exchangeable potassium, calcium carbonate, and organic carbon content of soils from unproductive areas and from adjoining areas of normal crop growth.*

Sample No.	Description of plants in July	Depth of soil samples, inches	Exchangeable potassium, lbs. per acre*	$CaCO_3$ %	Organic carbon %
		Patterson Field			
1	Deficiency symptoms	0 6 6-12	205 143	26.0 17.4	7.9
2	Normal growth	0-6 6 12	381 287	9.2 3.6	5.7
		Nolte Field			
3	Deficiency symptoms	0 6 6-12	148 123	18.7 6.0	6.9
4	Normal growth	0 6 6 12	196 169	18.0 17.6	7.8
5	Normal growth	0 6 6-12	273 277	2.5 1.8	5.1
		DeWolf Field			
6	Deficiency symptoms	0-6 6 12	148 128	20.8 22.7	5.5
7	Normal growth	0-6 6-12	401 376	21.4 23.1	6.4
8	Normal growth	0-6 6-12	317 291	3.2 3.0	4 0
		Carlson Field			
9	Deficiency symptoms	0-6 6-12	162 87	21.7 22.5	5.1
10	Normal growth	0-6 6 12	952 789	11.6 13.7	5.9
11	Normal growth	0-6 6 12	1,780 1,759	16.2 22.8	7.3
		Barnes Field			
12	Deficiency symptoms	0-6 6-12	85 78	27.6 39.5	6.7
13	Normal growth	0-6 6-12	185 84	25.5 34.2	7.3
		Conway Field			
14	Deficiency symptoms	0-6 6-12	189 96	30.7 34.8	8.6
15	Deficiency symptoms	0-6 6-12	164 53	32.6 41.9	8.8
16	Normal growth	0-6 6-12	392 210	12.8 11.3	7.0

TABLE 2.—*Concluded.*

Sample No.	Description of plants in July	Depth of soil samples, inches	Exchangeable potassium, lbs. per acre*	$CaCO_3$ %	Organic carbon %
		Vaudte Field			
17	Deficiency symptoms	0–6	195	13.4	5.6
		6–12	171	12.0	
		Whittemore Field			
18	Normal growth	0–6	278	9.4	5.6
		6–12	241	8.2	
		Bennett Field			
19	Normal growth	0–6	178	12.6	4.3
		6–12	97	11.3	
20	Deficiency symptoms	0–6	136	35.6	5.2
		6–12	68	33.8	
		Erickson Field			
21	Deficiency symptoms	0–6	107	20.6	4.7
		6–12	98	13.4	
22	Normal growth	0–6	189	6.4	6.8
		6–12	175	2.5	
		Average†			
	Deficiency symptoms	0–6	151	24.0	6.1
	Normal growth	0–6	396	12.5	6.2

*Calculated on basis of 2,000,000 pounds of soil per acre 6⅔ inches

†When two samples of soil showing the same type of plant growth were taken from one field, the analyses of the two samples were averaged and considered as one figure in computing the average for all fields.

POTASSIUM FIXATION STUDIES

The results of the study on potassium fixation are shown in Table 3. In every case the unproductive soil fixed more potassium than the productive soil from the same field, the average fixation being 211 pounds of potassium per 2 million pounds of soil for the former and only 105 pounds for the latter. One of the unproductive soils, number 3A, fixed all of the potassium added and 71 pounds per acre of potassium which was originally exchangeable, a total fixation of 323 pounds. The lowest amount of potassium fixed by any unproductive soil was 111 pounds per acre. Sample 11A, which supported normal corn growth, not only showed no potassium fixation but released 88 pounds of potassium per 2 million pounds of soil during the time that it was allowed to stand in a moist condition.

The potassium-fixing power of 10 non-calcareous soils, which represent some of the more extensive soil types in Iowa, was determined by the same methods as were used on the soils from fields containing un-

TABLE 3.—*Potassium fixation by productive and unproductive high-lime soils.**

Sample No.	Nature of soil	Original exchangeable K, lbs. per acre	K fixed, lbs. per acre
	Patterson Field		
1A	Unproductive	205	194
2A	Productive	381	161
	Nolte Field		
3A	Unproductive	148	323
4A	Productive	196	171
5A	Productive	273	157
	DeWolf Field		
6A	Unproductive	148	265
7A	Productive	401	141
8A	Productive	317	213
	Carlson Field		
9A	Unproductive	162	230
10A	Productive	952	49
11A	Productive	1,780	88†
	Barnes Field		
12A	Unproductive	85	228
13A	Productive	185	123
	Conway Field		
14A	Unproductive	189	151
15A	Unproductive	164	170
16A	Productive	392	90
	Vaudte Field		
17A	Unproductive	195	182
18A	Productive	278	120
	Bennett Field		
19A	Productive	178	56
20A	Unproductive	136	111
	Erickson Field		
21A	Unproductive	107	205
22A	Productive	189	75
	Average		
	Unproductive	151	211
	Productive	396	105

*Calculated on basis of 2,000,000 pounds of soil per acre 6⅔ inches.
†Released rather than fixed.

productive high-lime areas. The original content of exchangeable potassium and the potassium-fixing power of these soils are given in Table 4. It is evident from the data that the non-calcareous soils fixed very little potassium, the average fixation for the 10 soils being only 13 pounds per 2 million pounds of soil.

TABLE 4.—*Potassium fixation by acid upland soils.*

Soil type	Soil group	Original exchangeable potassium, lbs. per acre	Potassium fixed, lbs. per acre*
Tama silt loam	Normal Prairie	638	−82
Edina silt loam	Planosol	179	24
Grundy silt loam	Planosol	429	24
Tama silt loam	Normal Prairie	660	6
Clarion loam	Young Prairie	366	47
Marshall silt loam	Normal Prairie	527	− 5
Marshall silt loam	Normal Prairie	1,114	10
Fayette silt loam	Gray Brown Podzolic	140	52
Clinton silt loam	Gray Brown Podzolic	283	44
Carrington loam	Normal Prairie	191	11
Average		453	13

*The amount of potassium chloride added to the soils was equivalent to 252 pounds of potassium per acre (2,000,000 lbs. soil).

STUDIES ON POTASSIUM LIBERATION

The results of the study on the liberation of potassium from the non-exchangeable form are shown in Table 5. As previously stated, the exchangeable potassium was removed from these soils before incubating them for 80 days at 30% moisture. The amount of exchangeable potassium found at the end of the incubation period, therefore, represents the amount liberated from non-exchangeable form. The amounts thus obtained ranged from 45 to 117 pounds of potassium per acre. In four of the five fields studied the productive soils liberated more potassium than the unproductive soils. The differences, however, are not great. One acid soil, the Edina silt loam, liberated about the same amount of potassium as most of the calcareous soils.

The fertilized soils that had received 850 pounds of potassium in the form of potassium chloride in growing two crops of corn released considerably higher amounts of potassium during the 80 days incubation period than the unfertilized soils. The actual differences are low, however, when compared with the large amounts added, corroborating the fact that these soils possess a high fixing power for potassium.

GENERAL DISCUSSION

The data given in Table 2 indicate that the differences in plant growth on the unproductive high-lime areas as compared to that on the adjacent soils may be due, at least partly, to differences in the

amounts of exchangeable potassium present. This is emphasized by the fact that the productive soils contained an average of 151% more exchangeable potassium than the unproductive soil from the same field.

TABLE 5.—*Potassium released from soils in 80 days following removal of the exchangeable potassium, expressed as pounds per acre.**

Field	Sample No.	Nature of soil	Original amount of exchange-able K	K released
DeWolf	6A	Unproductive	148	52
	8A	Productive	317	69
Barnes	12A	Unproductive	85	65
	13A	Productive	185	79
Vaudt	17A	Unproductive	195	64
	18A	Productive	278	78
Nolte	G1†	Unproductive	138	60
	G2	Productive	250	54
	G1	Unproductive, fertilized	294	87
	G2	Productive, fertilized	441	67
Carlson	G3	Unproductive	180	45
	G4	Productive	440	70
	G3	Unproductive, fertilized	399	113
	G4	Productive, fertilized	841	117
Edina		Planosol	179	72
Average		Unproductive, unfertilized	149	57
		Productive, unfertilized	294	70

*Calculated on basis of 2,000,000 pounds soil per acre 6⅔ inches.

†The prefix G shows that the soils had been used in plant response studies in the greenhouse. The fertilized pots received a total of 850 pounds of potassium per acre in the form of potassium chloride. The two plantings of corn on these pots were harvested after 30 and 36 days, respectively.

When comparisons are made of soils from different fields, however, it becomes evident that certain of the soils which supported normal corn growth were lower in exchangeable potassium than some of the unproductive soils from other fields. It is apparent, therefore, that in addition to the actual amount of exchangeable potassium present other factors influence the response of plants to potassium fertilization on these soils. One of these factors may be the calcium-potassium ratio in the soil solution, for various workers have pointed out that excessive amounts of available calcium may exert a depressive effect upon the absorption of potassium by plants (8, 9, 14, 20).

Sears (17) found that the unproductive high-lime soils of Illinois contained excessively high amounts of nitrates and concluded that this was partially responsible for the low productivity of these soils. Since these soils contained large amounts of calcium carbonate, it is quite likely that the nitrates were present as calcium nitrate. Thus, a high concentration of nitrates would mean a large amount of soluble calcium and a wide calcium-potassium ratio in the soil solution, a condition that would decrease the absorption of potassium by plants.

A number of investigators have studied the amount of potassium necessary for good crop growth. Bray (3) concluded that soils that contain 140 pounds or more of exchangeable potassium per acre in the surface 6⅔ inches will give good crop growth on well-managed corn belt soils, that soils containing from 90 to 140 pounds will probably respond to potassium fertilization, and that those below 90 pounds will show good responses to potassium fertilization.

Volk and Truog (21) place the dividing line between potassium deficient soils and those not deficient at about 165 pounds of exchangeable potassium per acre.

Murphy (15) states that soils of Oklahoma which contain more than 120 pounds of exchangeable potassium per acre will usually support good crop growth, although occasional responses to potassium fertilization may be obtained on soils containing up to 200 pounds per acre.

As shown in Table 2, corn made very poor growth and showed signs of extreme potassium deficiency on some of the high-lime soils of this study, even though they contained from 140 to 200 pounds of exchangeable potassium per 2,000,000 pounds of surface soil. Since the investigations of Bray, Volk and Truog, and Murphy indicate that soils with this amount of exchangeable potassium should be only slightly deficient, it is evident that more exchangeable potassium is necessary for good plant growth on high-lime soils than on the normally acid soils of central United States which were studied by these investigators. This difference may likewise be due to calcium-potassium antagonism in high-lime soils.

The unproductive soils generally contained more calcium carbonate than the productive soils from the same field, although some of the productive soils were quite high in calcium carbonate content. This indicates that the calcium carbonate content of these soils is not the controlling factor in determining the productivity of the two types of areas. For example, soils 6 and 7 contained practically the same amounts of carbonate, although the latter produced almost twice as much corn as the former. However, soil 7 contained about three times as much exchangeable potassium as soil 6, which probably accounts for the difference in productivity. The same relationship is shown by comparing soils 3 and 4 and also soils 12 and 13.

The data on potassium fixation indicate that differences in the potassium-fixing power of productive and unproductive soils may account partly for the differences in the amounts of available potassium present and therefore be the underlying cause of potassium deficiency in the former soils. It is of interest to note that the potassium-fixing power of the acid soils was very low in comparison to that of the calcareous soils. This no doubt explains the fact that in field experiments very little residual effects have been observed from heavy broadcast applications of potash fertilizers.

The results of the study on the liberation of potassium from the non-exchangeable form indicate that liberation may be slightly more rapid in the soils which supported good crop growth. The differences, however, do not seem to be large enough to explain the difference in crop growth obtained on the two types of areas.

SUMMARY AND CONCLUSIONS

Unproductive high-lime soils from nine different fields in north central Iowa were compared with soils from the same fields which supported normal crop growth. The results may be summarized as follows:

1. Within any given field the productive soil contained from 31 to over 700% more exchangeable potassium than the unproductive soil. The latter averaged 151 pounds of exchangeable potassium per acre (2 million pounds), whereas the productive soils averaged 396 pounds.

2. Seven of the 10 unproductive soils contained less than 175 pounds of exchangeable potassium per acre, whereas all 12 of the productive soils contained more than this amount.

3. The unproductive soil was generally higher in calcium carbonate than the productive soil from the same field, the average content of the former being 24.0%, and of the latter 12.6%.

4. Eight of the 12 productive soils contained less than 15% calcium carbonate in the surface 6 inches, whereas 9 of the 10 unproductive soils contained more than this amount.

5. In every field, the unproductive soil showed a greater potassium-fixing power than the productive soil. The average amount of potassium fixed by 10 unproductive calcareous soils was 211 pounds per acre, by 12 calcareous productive soils 105 pounds, and by 10 acid soils only 13 pounds.

6. In four out of five fields studied the productive soils showed a more rapid liberation of non-exchangeable potassium, although the differences were relatively small.

From these results it may be concluded that:

1. Differences in the amounts of exchangeable potassium present may account, at least in part, for the differences in plant growth between unproductive high-lime soils and adjacent soils which support normal plant growth.

2. The high-lime soils of Iowa apparently require more exchangeable potassium in order to support good crop growth than do the normally acid soils of central United States.

3. Excessively high concentrations of calcium carbonate and bicarbonate may contribute, either directly or indirectly, to the low productivity of these soils.

4. On the basis of the relatively few soils studied in this investigation, it would appear that soils of north central Iowa which contain more than 15% calcium carbonate and less than 175 pounds of exchangeable potassium per acre will likely show signs of extreme potassium deficiency and respond markedly to potassium fertilization. Some high-lime soils containing more than this amount of exchangeable potassium may also give good response to potassium fertilization.

5. The high potassium-fixing power of unproductive high-lime soils may be responsible for the relatively low amounts of exchangeable potassium in these soils no doubt explains the small residual effects obtained from applications of potassium fertilizers.

LITERATURE CITED

1. ABEL, F. A. E., and MAGISTAD, O. C. Conversion of soil potash from the non-replaceable to the replaceable form. Jour. Amer. Soc. Agron., 27:437–445. 1935.
2. BANCROFT, R. L. The "alkali" soils of Iowa. Iowa Agr. Exp. Sta. Bul. 177. 1918.
3. BRAY, R. H. Calibrating soil tests for available potassium. Proc. Soil Sci. Soc. Amer., 1:175–179. 1937.
4. ——— and DETURK, E. E. The release of potassium from non-exchangeable forms in Illinois soils. Proc. Soil Sci. Soc. Amer., 3:101–106. 1938.
5. BROWN, D. S., ROBINSON, R. R., and BROWNING, G. M. Determination of small amounts of potassium. Ind. and Eng. Chem., Anal. Ed., 10:652–654. 1936.
6. COOPER, H. P., SHRIENER, O., and BROWN, B. E. Soils and Men. U.S.D.A. Yearbook of Agriculture: 397–405. 1938.
7. DEAN, H. C. The effects of liming on the liberation of potassium in some Iowa soils. Iowa Agr. Exp. Sta. Res. Bul. 197. 1936.
8. FONDER, F. J. Variations in potassium content of alfalfa due to stage of growth and soil type and the relationships of potassium and calcium in plants grown on different soil types. Jour. Amer. Soc. Agron., 21:732–750. 1929.
9. GEDROIZ, K. K. Exchangeable cations in the soil and the plant. I. Relation of the plant to certain cations fully saturating the exchange complex. Soil Sci., 32:51–63. 1931.
10. HOAGLAND, D. R., and MARTIN, J. C. Absorption of potassium by plants in relation to replaceable, non-replaceable and soil solution potassium. Soil Sci., 36:1–33. 1933.
11. KILPATRICK, B. M. Corn on alkali soils responds to potash. Better Crops With Plant Food: 22:13–16; 38–42. 1938.
12. KOLODNY, LEO. The mechanism of potassium fixation and the availability of fixed potassium to plants. Unpublished Ph.D. thesis, Rutgers University. 1938.
13. MCGEORGE, W. T. Potassium in calcareous soils. Part I. Solubility and availability. Part II. Some properties of replaceable potassium. Ariz. Agr. Exp. Sta. Tech. Bul. 50. 1933.
14. MCCOOL, M. C., and WELDON, M. D. The effect of soil type and fertilization on the expressed sap of plants. Jour. Amer. Soc. Agron., 20:778–792. 1926.
15. MURPHY, N. J. The replaceable potassium content compared with field response to potash fertilization of some Oklahoma soils. Jour. Amer. Soc. Agron., 26:34–37. 1934.
16. PROEBSTING, E. L. Absorption of potassium by plants as affected by decreased exchangeable potassium in the soil. Jour. Pomol. and Hort. Sci., 11:199–204. 1933.
17. SEARS, O. H. Relation of nitrates in soils to response of crops to potash fertilization. Factors contributing to unproductiveness of alkali soils of Illinois. Soil Sci., 30:325–345. 1930.
18. STEVENSON, W. H., and BROWN, P. E. Improving Iowa's peat and alkali soils. Iowa Agr. Exp. Sta. Bul. 157. 1915.
19. ———, ———, and BOATMAN, J. L. The management of peat and alkali soils of Iowa. Iowa Agr. Exp. Sta. Bul. 266. (Dec. 1937 reprint.)
20. VAN ITALLIE, T. H. Cation equilibrium in plants in relation to soil. Soil Sci., 46:175–186. 1938.
21. VOLK, G. W. The nature of potash fixation in soils. Soil Sci., 45:263–276. 1938.
22. VOLK, N. J., and TRUOG, E. A rapid chemical method for determining the readily available potash of soils. Jour. Amer. Soc. Agron., 26:537–546. 1934.
23. ———. The fixation of potash in difficultly available form in soils. Soil Sci., 37:267–287. 1934.
24. WALKLEY, A., and BLACK, I. A. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci., 37:29–37. 1934.

GERMINATION OF THE SEED OF POVERTY GRASS, *DANTHONIA SPICATA*[1]

VIVIAN KEARNS TOOLE[2]

POVERTY grass, *Danthonia spicata* (L.) Beauv., is a perennial with rather wide distribution on poor soils throughout the eastern United States. Because of the ability of this grass to grow on poor and eroded soil, it may have some value for erosion control work. Two samples collected in the Shenandoah National Forest by D. W. Levandowsky were submitted by M. M. Hoover of the Soil Conservation Service with the request that experiments be made to determine the germination requirements of this seed. No published information has been found on the germination requirements of *Danthonia spicata.*

The writer will not attempt to review the extensive literature on the occurrence of dormancy of seeds and methods for overcoming dormancy which has been reviewed by Crocker (2, 3),[3] Toole (7), and others.

The greater part of the work on sulfuric acid treatment of seeds deals with cotton and legumes and will not be reviewed here. Burton (1) has recently published on the beneficial effect of treatment with sulfuric acid on several species of southern grasses and found that crude sulfuric acid of approximately 78% strength could be used successfully. Stoddart and Wilkinson (6) showed that the seed of *Oryzopsis hymenoides*, a western grass, is benefitted by treatment with concentrated sulfuric acid, the length of treatment giving best results depending on the size of the seed. Huntamer (4) found a 5-minute treatment with concentrated sulfuric acid beneficial for *O. hymenoides*.

MATERIALS AND METHODS

As stated above, two samples were used in these experiments. Samples No. 1 and No. 2 presumably of 1938 harvest were received on August 29 and December 22, 1938, respectively. Apparently both samples were from the same original bulk, the difference in results with the two samples being due to difference in storage conditions. Sample No. 1 was stored as a small sample in the laboratory during the 4 months that sample No. 2 remained in bulk storage.

The seed as received was cleaned by means of an air blast blower. Both samples contained approximately 77% of heavy caryopses. Only the heavy caryopses were used in this study. The seed was placed for germination in Petri dishes on paper toweling saturated with tap water or with a 0.2% solution of potassium nitrate. Tests were made in duplicate. The seed was germinated at both constant and alternating temperatures. The alternation of temperature was secured by transferring the test from one germination chamber to another, the test remaining

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[2]Junior Botanist. Grateful acknowledgment is made to E. H. Toole for his suggestions and criticisms throughout these investigations, and to V. R. Boswell for his assistance with the statistical analysis.

[3]Figures in parenthesis refer to "Literature Cited", p. 965.

at the first temperature listed for 17 and at the second temperature for 7 hours out of each 24 hours. The temperature of the germination chambers was controlled within 1 degree of that listed. In order to obtain light exposure accompanying a high temperature alternation, the test was placed in a north window of an air-conditioned building for the 17-hour period. The room temperature varied from 16° to 24° C.

To prechill the seed it was placed on moistened paper toweling and held at 3° or at 10° C for various lengths of time. The temperature of the 3° chamber varied between 2° and 5° C. The time of counting is dated from the day the seed was placed to prechill and not from the day the seed was transferred to the germination temperature.

To treat the seed with sulfuric acid, the seed was placed in a small porcelain crucible, covered with an excess of acid, and stirred constantly for the designated time. The treated seed then was washed in running tap water for 30 to 45 minutes and dried thoroughly before placing to germinate. The approximately 71% sulfuric acid used was made by diluting 3 parts of concentrated sulfuric acid (sp. gr. 1.84 and at least 94%) with 1 part distilled water by volume.

The sprouts were counted at regular 7-day intervals. Those seeds were considered as germinated which produced a normally developed seedling.

Germination figures summarized in Tables 1, 3, and 5 are in all cases mean values, based on duplicate tests of 100 seeds each. Values for "error" and tests of significance of differences have been calculated by the analysis of variance method as adapted by Snedecor (5).

PRESENTATION OF RESULTS

The study of various pretreatments with prechilled temperatures and with sulfuric acid, of the effect of potassium nitrate, and of the effect of two germination temperatures on the two samples of seed was broken down for simplification of presentation into Tables 1 to 6, inclusive.

GERMINATION AT VARIOUS TEMPERATURES

Sample No. 1, when first received, was germinated at the constant temperatures of 10°, 15°, 20°, 25°, and 30° C, and at the alternating temperatures of 10° to 25°, 15° to 25°, 20° to 30°, 20° to 35°, and 20° to 40°, each with water and with 0.2% solution of potassium nitrate. Since 15% was the highest germination obtained in 63 days, the data hardly require presentation in tabular form. Prechilling at 3° and at 10° followed by germination at alternating temperatures gave higher results that suggested the value of further work along this line.

PRECHILLING TREATMENT

In January, 1939, seed of sample No. 2 was prechilled at 3° C and at 10° for 14, 21, and 28 days, then germinated at 10° to 25° and at room temperature to 35°, with and without the use of potassium nitrate. The results are given in Table 1 and the analysis of variance is given in Table 2. The mean of all tests prechilled at 3° is significantly better than the mean of all tests prechilled at 10°. There is a significant difference between the two prechilling temperatures when germinated at 10° to 25° and a highly significant difference between

the two prechillings when germinated at room temperature to 35°. Prechilling at 3° is decidedly better than at 10° when germinated at either room temperature to 35° or at 10° to 25° with the use of tap water and at room temperature to 35° with the use of potassium nitrate. The differences in germination among the tests that were prechilled different numbers of days were quite variable, being significant in some cases showing a progressive benefit with longer treatment at the 3° prechilling temperature. Prechilling at 3° for 63 days appears to be the most effective. Greater differences in germination were generally observed among the various times of prechilling than be-

TABLE I.—*Germination in 119 days of seed of Danthonia spicata (sample No. 2) at indicated temperatures with specified treatment, means of duplicate 100 seed tests.**

Germination temperature, °C	Treatment of medium	Duration of prechilling, days	Percentage germination response to prechilling treatment at			Mean	
			Number of observations	3° C	10° C	Number of observations	Germination, %
10° to 25°	Nitrate	14	2	21.5	32.5	4	27.0
		28	2	53.5	41.5	4	47.5
		63	2	87.0	83.5	4	85.25
		Mean	6	54.0	52.5	12	53.25
	Water	14	2	5.0	4.5	4	4.75
		28	2	11.5	5.0	4	8.25
		63	2	76.0	48.0	4	62.00
		Mean	6	30.8	19.1	12	24.9
	Mean	14	4	13.25	18.5	8	15.87
		28	4	32.5	23.25	8	27.87
		63	4	81.5	65.75	8	73.62
		Mean	12	42.4	35.8	24	39.1
Room to 35°	Nitrate	14	2	65.5	59.5	4	62.5
		28	2	79.0	75.0	4	77.0
		63	2	87.0	47.0	4	67.0
		Mean	6	77.1	60.5	12	68.8
	Water	14	2	27.5	35.5	4	31.5
		28	2	62.5	42.0	4	52.25
		63	2	69.0	44.0	4	56.5
		Mean	6	53.0	40.5	12	46.75
	Mean	14	4	46.5	47.5	8	47.00
		28	4	70.75	58.5	8	64.62
		63	4	78.0	45.5	8	61.75
		Mean	12	65.05	50.5	24	57.77

*Minimum differences required for significance are: Between means of 2 observations 20.12%; between means involving 4 observations 12.12%; 6 observations 9.00%; 8 observations 7.50%; 12 observations 5.96%; 16 observations 5.06%; 24 observations 4.05%.

TABLE 1.—*Concluded.*

Germination temperature, °C	Treatment of medium	Duration of prechilling, days	Percentage germination response to prechilling treatment at			Mean	
			Number of observations	3° C	10° C	Number of observations	Germination, %
Mean	Nitrate	14	4	43.5	46.0	8	44.75
		28	4	66.25	58.25	8	62.25
		63	4	87.0	65.25	8	76.12
		Mean	12	65.5	56.5	24	61.00
	Water	14	4	16.25	20.0	8	18.12
		28	4	37.0	23.5	8	30.25
		63	4	72.5	46.0	8	59.25
		Mean	12	41.9	29.8	24	35.85
	Mean	14	8	29.87	33.00	16	31.43
		28	8	51.62	40.87	16	46.24
		63	8	79.75	55.62	16	67.68
		Mean	24	53.72	43.16	48	48.43

TABLE 2.—*Analysis of variance of germination data in Table 1.*

Source of variation	Degrees of freedom	Mean square
Total	47	724.08
Prechilled temperatures (3° and 10° C)	1	1,344.08*
Germination temperatures (10–25 and R-35)	1	4,181.33*
Treatments (No. of days prechilled)	2	5,314.77*
Between KNO_3 and H_2O	1	7,600.33*
Prechilled temperatures × germination temperature	1	192.01†
Prechilled temperatures × treatment	2	742.65*
Prechilled temperatures × nitrate	1	27.01†
Germination temperature × treatment	2	2,830.02*
Germination temperature × nitrate	1	114.09†
Treatment × nitrate	2	235.15‡
Prechilled temperature × germination temperature × treatment	2	57.84†
Prechilled temperature × germination temperature × nitrate	1	154.07†
Germination temperature × nitrate × treatment	2	167.64‡
Prechilled temperature × treatment × nitrate	2	13.68†
Prechilled temperature × germination temperature × treatment × nitrate	2	259.74‡
Error	24	49.00

*Variances are highly significant with reference to error.
†Not significant with reference to error.
‡Significant with reference to error.

tween the prechilling temperatures used. The greatest difference in nitrate response was associated with the shorter prechilling periods. The proportional effect of nitrate versus water is approximately the same at both germination temperatures and at the two prechilling temperatures.

TREATMENT WITH CONCENTRATED SULFURIC ACID

Treatment of the seed with concentrated sulfuric acid for 1, 3, and 5 minutes in October, 1938, and then germinating the seed at 10° to 25°, 20° to 30°, and at room temperature to 35° C gave higher results than the check test at the same temperatures. The best results (43% germination) were obtained with a 5-minute acid treatment followed by germination at room temperature to 35°. However, some of the seeds apparently were injured and some still remained sound and ungerminated.

TREATMENT WITH APPROXIMATELY 71% SULFURIC ACID

In January, 1939 at the time the prechilling experiment was conducted, seed from samples Nos. 1 and 2 was also treated with 71% sulfuric acid for 0, 15, 30, and 45 minutes and then germinated at 10° to 25° and at room temperature to 35° C. The tests were in duplicates of 100 seeds each with 0.2% solution of potassium nitrate and with water. The results for the 28 and 119 day counts are given in Table 3, and the analysis of variance in Table 4.

The results of the analysis of variance indicate highly significant differences in germination due to each of the several single factors studied. Nearly all interactions were also significant. The difference in response of the two samples probably was due to the fact that the sample stored in the laboratory for the longer period had dried out more and was therefore more resistant to germination. The room temperature to 35° germination temperature was strikingly better than 10 to 25°. Potassium nitrate induced a higher percentage germination in 28 days at 10° to 25° but not at room temperature to 35°; the increase is generally evident at both temperatures by 119 days. Pretreatment with 71% sulfuric acid for 30 to 45 minutes and then germinating at room temperature to 35° C with the use of potassium nitrate afforded the optimum condition. With sample No. 1, 15 minutes was not long enough acid treatment to give the best results, but longer treatment than 30 minutes did not seem to be necessary. With sample No. 2 there was no significant difference among the three acid treatments when germinated at room temperature to 35°.

As stated above the optimum condition for the germination of this seed requires careful control of not one major factor but of several factors, as shown by the high significance of the interactions involved.

There is a significant difference in the response of the two samples at the two germination temperatures, the greater difference between samples being at 10° to 25° C. This sample difference had decreased by the final count but was still of significance. The difference in response of the two samples to nitrate was somewhat variable and of doubtful importance. At 28 days the samples showed greater variance

in response to the germination temperature than to nitrate, but by the final count at 119 days the variance due to nitrate was greater than that due to the germination temperature. At 28 days the untreated seed were little affected by nitrate, but by 119 days there was a greater effect of nitrate on the untreated samples. The high variance due to acid treatments was brought about mainly by the low value of the zero time treatment.

DOUBLE TREATMENT WITH APPROXIMATELY 71% SULFURIC ACID

The results obtained in the preceding experiment showing approximately 85% germination or better appeared to represent the full value of the sample since the seeds either germinated or decayed Some of the treated tests resulted in about 10% lower germination with sound seeds remaining at the end of the experiment. The writer thought that perhaps a short time of treatment of the seed with acid, thoroughly washing and drying, and followed by another short period of treatment, thoroughly washing and drying, might give a more uniform response. Treatments of 15 and 15, 15 and 30, 30 and 15, 30 and 30, 45 and 15, and 45 and 30 minutes were tried. The seed was then put to germinate at 10° to 25° and at room temperature to 35° C with and without the use of potassium nitrate. In every case there was decided injury to the seed. Sample No. 1 treated 15 and 15 minutes and tested at room temperature to 35° germinated 34 and 29% with the use of potassium nitrate and water, respectively. Contrast this with the 30-minute treatment shown in Table 3. The longer the period of the two treatments, the greater was the injury to the seed

ACID TREATMENT VERSUS PRECHILLING

The 45-minute treatment with 71% sulfuric acid and the 3° C prechilling tests were selected for this comparison. There was no significant difference between the prechilled 63-day and the 45-minute acid treatment tests at 10° to 25° with potassium nitrate or with water; at room temperature to 35° there was a significant difference with water but not with potassium nitrate. The 45-minute acid treatment was significantly better than the 14 and 28 days prechilling when germinated at either temperature. The final germination results are given in Table 5 and analysis of the variance of data in Table 6.

PRECHILLING IN ADDITION TO ACID TREATMENT

Seed of the two samples treated with 71% sulfuric acid for 15, 30, and 45 minutes was prechilled at 10° C for 28 days before subjecting them to the germination temperature, room temperature to 35° C.

As shown in Table 3, the acid treatment alone brought about maximum germination in most cases. However, prechilling was of no additional benefit on the 15-minute acid treatment with water that gave incomplete germination of the viable seed. The results are not given in tabular form.

TABLE 3.—*Germination of seed of Danthonia spicata at indicated temperatures after being treated with approximately 71% H_2SO_4 for various times, means of duplicate 100 seed tests.**

Germination temperature, °C	Treatment of medium	Sample No.	No. of observations	Percentage germination response to acid treatment for time shown: None	15 min.	30 min.	45 min.	Mean: No. of observations	Germination, %
28 Days in Germinator									
10° to 25°	Nitrate	1	2	2.0	29.0	35.0	55.0	8	30.25
		2	2	9.5	66.5	57.0	72.0	8	51.25
		Mean	4	5.75	47.75	46.0	63.5	16	40.75
	Water	1	2	3.0	17.5	24.5	44.5	8	22.37
		2	2	6.0	39.5	35.0	63.5	8	36.0
		Mean	4	4.5	28.5	29.75	54.0	16	29.18
	Mean	1	4	2.5	23.25	29.7	49.75	16	26.31
		2	4	7.7	53.0	46.0	67.75	16	43.62
		Mean	8	5.1	38.12	37.85	58.75	32	34.96
Room to 35°	Nitrate	1	2	8.5	64.5	79.0	73.5	8	56.37
		2	2	22.5	82.0	74.0	79.5	8	64.5
		Mean	4	15.5	73.25	76.5	76.5	16	60.43
	Water	1	2	9.0	62.5	80.5	80.5	8	58.12
		2	2	22.0	74.0	72.0	84.0	8	63.0
		Mean	4	15.5	68.25	76.25	82.25	16	60.56
	Mean	1	4	8.75	63.5	79.75	77.0	16	57.24
		2	4	22.25	78.0	73.0	81.75	16	63.75
		Mean	8	15.5	70.75	76.37	79.37	32	60.49
Mean for 28 days			16	10.3	54.43	57.22	69.06		47.72

119 Days in Germinator

10° to 25°	Nitrate	1	2	34.5	77.5	79.0	81.5	8	68.12
		2	2	32.5	81.5	83.5	83.0	8	70.12
		Mean	4	33.5	79.5	81.25	82.25	16	69.12
	Water	1	2	5.5	29.5	46.0	59.0	8	35.0
		2	2	9.5	55.5	55.5	75.5	8	49.00
		Mean	4	7.5	42.5	50.75	67.25	16	42.0
	Mean	1	4	20.0	53.5	62.5	70.25	16	51.56
		2	4	21.0	68.5	69.5	79.25	16	59.56
		Mean	8	20.5	61.0	66.0	74.75	32	55.56
Room to 35°	Nitrate	1	2	27.5	84.0	88.0	83.5	8	70.75
		2	2	48.0	85.5	89.0	83.5	8	76.5
		Mean	4	37.75	84.75	88.5	83.5	16	73.62
	Water	1	2	12.5	70.0	86.5	84.0	8	63.25
		2	2	25.0	77.5	78.0	86.0	8	66.62
		Mean	4	18.75	73.75	82.25	85.0	16	64.93
	Mean	1	4	20.0	77.0	87.25	83.75	16	67.0
		2	4	36.5	81.5	83.5	84.75	16	71.56
		Mean	8	28.25	79.25	85.37	84.25	32	69.28
Mean for 119 days			16	24.37	70.12	75.68	79.5	64	62.42

*Differences required for significance in the 28-day test between means of two observations 19.44%; between means involving 4 observations 7.82%; 8 observations 4.84%; 16 observations 3.26%; 32 observations 2.26%. Differences required for significance in the 119-day test between means of 2 observations 11.35%; between means involving 4 observations 4.57%; 8 observations 2.83%; 16 observations 1.91%; 32 observations 1.32%.

TABLE 4.—*Analysis of variance of germination data in Table 3.*

Source of variation	Degrees of freedom	28 days mean square*	119 days mean square*
Total	63	801.66	711.23
Temperatures	1	10,429.52	3,011.26
Between KNO_3 and H_2O	1	523.27	5,130.14
Between samples	1	2,268.15	631.26
Between acid treatment	3	10,604.81	10,530.89
Temperature × KNO_3	1	546.39	1,359.77
Temperature × sample	1	467.63	47.27†
Temperature × acid treatment	3	629.72	141.27
KNO_3 × sample	1	112.89†	92.64
KNO_3 × acid treatment	3	117.56	243.89
Sample × acid treatment	3	216.43	55.26
Temperature × KNO_3 × sample	1	17.02‡	206.64
Temperature × KNO_3 × acid	3	48.93‡	75.18
Temperature × sample × acid	3	179.18	160.93
Sample × acid × nitrate	3	22.18‡	60.56
Sample × KNO_3 × acid × temperature	3	9.89‡	100.38
Error	132	20.42	6.98

*Unless otherwise indicated, variances are highly significant with reference to error.
†Significant with reference to error.
‡Not significant with reference to error.

TABLE 5.—*Germination in 119 days of seed of Danthonia spicata (sample No. 2) at the indicated temperatures with specified treatment, means of duplicate 100 seed tests.**

Germition temperature, °C	Treatment of medium	Percentage germination of tests pretreated as shown: No. of observations	Prechilled for 14 days	Prechilled for 28 days	Prechilled for 63 days	Acid 45 min.	Mean: No. of observations	Mean: Germination, %
10° to 25°	Nitrate	2	21.5	53.5	87.0	83.0	8	61.25
	Water	2	5.0	11.5	76.0	75.0	8	42.00
	Mean	4	13.25	32.5	81.5	79.0	16	51.62
Room to 35°	Nitrate	2	65.5	79.0	87.0	88.5	8	78.7
	Water	2	27.5	62.5	69.0	86.0	8	61.2
	Mean	4	46.5	70.75	78.0	87.25	16	69.95
Mean	Nitrate	4	43.5	66.25	87.0	85.75	16	69.97
	Water	4	16.25	37.00	72.5	80.5	16	51.60
	Mean	8	29.87	51.62	79.75	83.12	32	60.78

*Minimum differences required for significance are: Between means of 2 observations 14.50%; 4 observations 6.60%; 8 observations 3.88%; 16 observations 2.52%; 32 observations 1.71%.

TABLE 6.—*Analysis of variance of germination data in Table 5.*

Source of variation	Degrees of freedom	Mean square*
Total	31	788.93
Temperature	1	2,701.12
Between KNO_3 and H_2O	1	2,701.12
Between treatments	3	4,930.87
Temperature × KNO_3	1	6.14
Temperature × treatment	3	840.37
KNO_3 × treatment	3	309.37
Temperature × KNO_3 × treatment	3	208.20
Remainder (error)	16	11.37

*All values, except temperature × KNO_3, are highly significant with reference to error.

WATER ABSORPTION

The seeds remaining sound at the end of the test period were firmer than sound seed remaining in tests of fescue. The sound seeds were more comparable to the few dormant seeds sometimes observed in fresh *Lolium multiflorum* from the West. The question arose as to whether the non-germinating seeds of Danthonia were really impermeable to water. Was the resistance to germination due to lack of water absorption?

A small experiment was set up to determine the amount of water, if any, absorbed by non-treated seed and by acid-treated seed of Danthonia. Because the glumes were removed by the acid treatment, in order to make the tests comparable, the glumes were removed from the untreated lots by a slight pressure with the finger at the base of the caryopsis. After weighing, the seed was immersed in water for 24- and 48-hour periods when weights were again determined. The results are given in Table 7.

TABLE 7.—*Determination by weight of the amount of water absorbed by the seed and glumes of Danthonia spicata.*

Sample No.	Material soaked in water	Acid pretreatment of seed, minutes	Percentage of water taken up in 10 minutes	Percentage of water taken up in 24 hours	Percentage of water taken up in 48 hours
1	Seed	None	——	30.55	35.91
	Glumes	None	——	53.86	57.87
2	Seed	None	3.11	28.48	35.55
	Glumes	None	45.04	42.54	42.54
2	Seed	15	——	33.09	37.63
2	Seed	30	——	37.45	39.41
2	Seed	45	——	34.93	37.20

The difference in the amount of water absorbed by the treated and untreated seed is slight, although the rate of absorption was somewhat slower in the untreated seed. It would seem probable that the

poor germination without acid or prechilling treatment is due to restrictions of gas exchange instead of, or in addition to, slower water absorption.

DISCUSSION

The poor germination of untreated seed of *Danthonia spicata* would seem to be due to coat restrictions rather than to embryo dormancy, since acid treatment of the seed allowed rather prompt and maximum germination. It is probable that the coats restrict gas exchange, because water absorption was considerable, although slow, with the untreated seeds. The most striking results from the study of the germination requirements of this seed are that, even after acid treatment or prechilling, temperature of germination, possibly light, and previous history of the sample are important factors. There is a high interaction, in many cases, between these factors as shown by the different response of the two samples to nitrate, to germination temperature, and to length of acid treatment, and by the different effect of nitrate depending on germination temperature and length of acid treatment or time of prechilling.

In some instances the effect of certain factors was more pronounced after 119 days germination than after 28 days, while in other instances differences that were evident at 28 days were much less so or had disappeared by 119 days.

SUMMARY

This experiment was planned to find out the conditions necessary for the maximum germination of the seed of poverty grass, *Danthonia spicata*. Two samples of seed collected in the Shenandoah National Forest were used in this study. Tests were run in duplicates of 100 seeds each.

Preliminary experiments with various constant and alternating temperatures revealed that more was involved than the factor of the germination temperature.

The alternating temperature of room temperature to 35° C afforded a better condition for germination than 10° to 25°.

Germination was stimulated by a dilute solution of potassium nitrate.

Prechilling at 3° C for 63 days before placing to germinate at room temperature to 35° or 10° to 25° brought about maximum germination where potassium nitrate was used. Less time of prechilling with potassium nitrate or prechilling with water gave erratic results. Prechilling at 10° was not as good as prechilling at 3°.

Pretreating the seed with 71% sulfuric acid for 30 to 45 minutes was equally as effective as prechilling at 3° C for 63 days and brought about the final results in a shorter time. Pretreating for 15 minutes was not long enough in some instances. Prechilling the seed at 10° in addition to the acid treatment was of no benefit.

Pretreating the seed with concentrated sulfuric acid for 1, 3, and 5 minutes produced injury. Apparently there is a very narrow range for treatment with concentrated sulfuric acid.

Double treatments with 71% sulfuric acid for 15 and 15, 15 and 30, 30 and 15, 30 and 30, 45 and 15, and 45 and 30 minutes caused excessive injury to the seeds and was less effective than the very short treatments with concentrated sulfuric acid.

The sample held in the laboratory for 4 months was more resistant to treatments than the sample recently received from bulk storage.

The seedcoat is not impermeable to water as are the coats of seeds designated as "hard" seeds.

Nontreated seed absorbed water at a slower rate than seeds that had been treated for 15, 30, and 45 minutes with 71% sulfuric acid.

The seedcoat of *Danthonia spicata* is apparently the inhibiting factor in delaying germination, but it seems probable that this is due to restriction of gas exchange since restriction of water absorption is small.

LITERATURE CITED

1. BURTON, GLENN W. Scarification studies on southern grass seeds. Jour. Amer. Soc. Agron., 31:179–188. 1939.
2. CROCKER, WILLIAM. Mechanics of dormancy in seeds. Amer. Jour. Bot., 3:99–120. 1916.
3. ———. Role of seed coats in delayed germination. Bot. Gaz., 42:265–291. 1906.
4. HUNTAMER, MAY Z. Dormancy and delayed germination of oryzopsis hymenoides. Unpublished thesis, State College of Washington. 1934.
5. SNEDECOR, G. W. Statistical methods applied to experiments in agriculture and biology. Ames, Iowa. 1937.
6. STODDART, L. A., and WILKINSON, K. J. Induced germination in orysopsis hymenoides for range reseeding. Jour. Amer. Soc. Agron., 30:763–768. 1938.
7. TOOLE, E. H. Physiological problems involved in seed dormancy. Proc. Int. Seed Testing Assoc. 8:33–41. 1936.

THE EFFECT OF CALCIUM ARSENATE UPON THE YIELD OF COTTON ON DIFFERENT SOIL TYPES[1]

CLARENCE DORMAN AND RUSSELL COLEMAN[2]

IN recent years the demand for insect control has made it necessary to apply relatively large amounts of arsenates to certain crops. This is particularly true in the South where dusting cotton with calcium arsenate for boll weevil control has become an important practice. Most of the applied arsenic reaches the soil, and some recent investigations have indicated that accumulated arsenic greatly reduces the productivity of certain soils.

In South Carolina, Cooper, *et al* (3)[3] found that coarse-textured soils, such as Norfolk and Durham, were seriously affected. Applications of only 50 pounds of calcium arsenate per acre greatly reduced the yield of cotton on Durham coarse sandy loam. The fine-textured dark-colored soils, such as Greenville, Cecil, and Davidson, were not seriously affected by arsenate applications commonly used to combat boll weevil. In Louisiana, Reed and Sturgis (8) found no detrimental effect upon cotton production but obtained a toxic effect upon rice following cotton dusted with calcium arsenate. The toxicity was greater in Crawley very fine sandy loam than in Crawley silty clay loam. Craft (4), investigating the use of trivalent arsenic for soil sterilization, found soil toxicity greatest in Fresno, a sandy loam, and least in Yolo, a clay loam.

As commonly practiced in the cotton-growing area, there is no regularity in the application of calcium arsenate, either in quantity applied or frequency of applications. The quantity applied per acre at each application may vary from 3 to 10 pounds, depending upon the size of the cotton, and the number of applications in a given season may vary from one to six.

However, the quantity of calcium arsenate which finds its way into the soil is not as great as might be expected. It probably will not exceed 30 pounds per acre annually over a period of years, even on well-managed farms in areas of intense cotton production.

The increasing use of arsenical compounds for insect control, the possibility of conditions necessitating larger applications, and the likelihood of an accumulative effect from calcium arsenate seem to require more exact knowledge. It is the purpose of this paper to show the effect of calcium arsenate treatments upon the cotton yields from several important soil types.

EXPERIMENTAL

SOILS

Used in this study were three upland soils, Memphis silt loam at Holly Springs, Mississippi, Houston clay loam at West Point, Mississippi, and Ruston sandy

[1]Contribution from the Agronomy Department, Mississippi Agricultural Experiment Station, State College, Miss., and from the Division of Cotton Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture, Mississippi Agricultural Experiment Station, Paper No. 13, New Series, March 23, 1939. Received for publication September 11, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 970.

loam at Poplarville, Mississippi, and two delta soils, Sarpy silty clay loam at Tallulah, Louisiana, and Sarpy fine sandy loam at Stoneville, Mississippi.

Memphis silt loam is a well-drained productive soil developed from loess. The areas lie adjacent to but above the bottomlands on both sides of the Mississippi River southward from the vicinity of St. Louis almost to the Gulf of Mexico.

Houston clay loam is a well-drained soil of the Blackland Prairies occurring chiefly in Texas, Mississippi, and Alabama. The surface soil is black or nearly black clay loam; the subsoil is generally grayish-yellow or yellow clay; the substratum consists of marl or chalk.

Ruston sandy loam is a well-drained soil of the Atlantic and Gulf Coastal Plain. The surface soil is grayish-brown sandy loam; the subsoil is reddish-brown friable sandy clay, with substratum of unconsolidated Coastal Plain materials. It is one of the most widely distributed soils of the Coastal Plain Region. The materials are generally medium or strongly acid throughout.

The soils called Sarpy silty clay loam and Sarpy fine sandy loam occur in the first bottoms of the Mississippi River. They are generally fertile soils composed of recent alluvium and are among the best cotton soils in the Mississippi Delta Region.

TREATMENTS

Field plats, 1/40 acre in size with three replications, were treated with the following amounts of calcium arsenate in 1935: 0, 50, 100, 200, 400, 800 and, 1,600 pounds per acre. All soil types received the same treatment except Sarpy silty clay loam. The test on this soil contained only two plats, 1/7 acre in size, one plat receiving 400 pounds of calcium arsenate in 1934 and every year thereafter for 5 years, making a total of 2,000 pounds, the other receiving no arsenate.

Calcium arsenate was broadcast on the treated plats and disced into the soil to a depth of 4 or 5 inches. Applications were made in the spring before cotton was planted.

Four hundred pounds of 4–8–4 were applied to all plats every year at planting time.

RESULTS AND DISCUSSION

The data in Tables 1 and 2 show the effect of calcium arsenate treatments upon the yield of cotton on the five soil types studies. It was planned to obtain at least four years' results on all soil types, but

TABLE 1.—*Average yield of cotton on several soil types treated with calcium arsenate.*

Pounds of calcium arsenate per acre	Houston clay loam, 3-year average	Memphis silt loam, 1-year average	Sarpy fine sandy loam, 1-year average	Sarpy silty clay loam, 5-year average
0	991	788	1,724	1,794
50	1,065	819	1,608	——
100	1,030	850	1,656	——
200	982	831	1,568	——
400	1,025	794	1,809	——
800	1,013	799	1,838	——
1,600	1,036	783	1,692	——
2,000 (400 lbs. every year)	——	——	——	1,178

cotton was only grown one year on Memphis silt loam and Sarpy fine sandy loam and three years on Houston clay loam. All results obtained are presented in Tables 1 and 2.

TABLE 2. - *Yield of cotton on Ruston sandy loam treated with calcium arsenate in 1935.*

Pounds of calcium arsenate per acre	Yield of seed cotton in pounds per acre				
	1935	1936	1937	1938	4-year average
0	708	1,145	1,314	1,120	1,072
50	882	1,275	1,490	1,164	1,203
100	868	1,446	1,630	1,340	1,321
200	570	1,262	1,608	1,170	1,152
400	490	912	822	1,220	861
800	584	758	655	932	732
1,600	240	0	206	566	253

On the Houston clay loam no harmful effect was obtained, either in plant growth or yield of cotton, even when as much as 1,600 pounds of calcium arsenate were applied to the soil. The yield was 1,036 pounds per acre which is slightly more than the yield of 991 pounds given by the untreated plats. Most arsenate-treated plats outyielded the untreated plats, but it is doubtful if these increases are significant.

The results on Memphis silt loam are very similar to those obtained on Houston clay loam. All plats treated with calcium arsenate yielded just as much as the one receiving no calcium arsenate.

Five years' results on Sarpy silty clay loam show that a treatment of 400 pounds of calcium arsenate every year did not affect the yield of cotton. The plat which received 2,000 pounds of calcium arsenate over a period of five years yielded 1,778 pounds and the untreated plat 1,794 pounds of seed cotton per acre. Oats planted on both plats after five years treatment showed no injury from the calcium arsenate. The calcium arsenate treatments used on this soil were much greater than the average yearly treatment which did not exceed 30 pounds per acre in the Mississippi Delta.

Although the cotton yields from the Sarpy fine sandy loam were inconsistent, they indicate that no injurious effect was obtained from the heavy calcium arsenate treatments which gave as much seed cotton per acre as the untreated plat.

The cotton results on Ruston sandy loam (Table 2) show a definite increased yield every year from the lighter applications. In 1935, immediately after the arsenate was applied, only the 50- and 100-pound plats gave an increase over the untreated plat, and applications heavier than the 100 pounds reduced the cotton yield. In 1936, however, the 200-pound plot, as well as the 50- and 100-pound plats, gave a marked increase over the untreated plat. In 1938, four years after the arsenate was applied, the 400-pound treatment also gave a significant increase over the untreated plat and even the 800- and 1,600-pound treatments had lost much of their toxicity.

These data show that the toxicity of calcium arsenate was reduced with time. Only four years were required for the toxic influence of 400 pounds of calcium arsentate to be lost. It is doubtful if as much as 200 pounds of calcium arsenate is ever applied within four years, and these results indicate that even this quantity would not cause a decrease in cotton yields. The four years' average show that the 50-, 100-, and 200-pound treatments yielded 131, 245, and 80 pounds per acre, respectively, more than no treatment. The heavier applications greatly decreased the cotton yields. The plats treated with 1,600 pounds of calcium arsenate averaged only 253 pounds, a decrease of 819 pounds of seed cotton per acre due to the arsenate.

The results suggest that no effect, either beneficial or deterimental, may be expected from calcium arsenate applications to cotton grown on Houston clay loam, Memphis silt loam, Sarpy silty clay loam, or Sarpy fine sandy loam. However, on Ruston sandy loam there is a beneficial effect upon the yield of cotton from light applications and a detrimental effect from heavy applications of calcium arsenate.

In order to investigate the cause of variations in cotton response on different soils, the pH value and the percentage of CaO, Fe_2O_3, and P_2O_5 were determined in each soil. The percentage of clay was also determined by the Boyoucos method (1). These data are shown in Table 3. Ruston sandy loam, the soil which was affected by the heavy arsenate treatments, was much more acid than the other soils. This agrees with results obtained by Cooper, *et al* (2) who found that high acidity seems to increase the toxic effect of heavy applications of calcium arsenate. Of course, the total CaO and Fe_2O_3 content is not indicative of the activity of these elements in fixing arsenic, but it is interesting to note that the percentage of CaO and Fe_2O_3 was much higher in the more tolerant soils, which agrees with the report of Greaves (5) that calcium may render arsenic somewhat insoluble, and with the findings of Cooper, *et al* (2) that lime and iron helped counteract the harmful effect of arsenic.

TABLE 3. *Important constituents of the soils.**

Soil type	pH	CaO, %	Fe_2O_3, %	Clay, %
Houston clay loam	6.2	1.53	4.22	48.0
Memphis silt loam	5.9	0.35	2.62	27.2
Ruston sandy loam	5.0	0.20	1.35	8.4
Sarpy fine sandy loam	6.2	1.00	2.62	25.8
Sarpy silty clay loam	6.3	1.24	3.85	24.0

*pH determined by potentiometer method; CaO and Fe_2O_3 determined by A. O. A. C. method

The quantity of clay present suggests further reason for arsenic fixation. Houston clay loam, an unaffected soil, contained 48% colloidal material, whereas Ruston sandy loam, the soil most injured by calcium arsenate, contained only 8.4%, which indicates that the colloidal material is largely responsible for arsenic fixation. High pH and high colloidal content, which carries a high percentage of Fe_2O_3, seem necessary to make a large quantity of arsenic sufficiently insoluble to render it non-toxic to crops.

The beneficial effect of applications of 50 and 100 pounds of calcium arsenate on Ruston sandy loam was surprising. Other determinations have shown that this soil contains only 6 p.p.m. of available phosphorus by the Truog method (9) as well as low total P_2O_5 content. Unpublished results have shown that cotton tests conducted on adjoining plats have given a good response to both phosphorus and lime. Therefore, it is believed that the stimulated yield is due to three causes: First, the calcium applied as calcium arsenate counteracts the acidity and acts as a nutrient. Second, the arsenic either liberates or partially substitutes for the unavailable phosphorus in the soil. Third, the light application of calcium arsenate stimulates the bacterial activities of the soil. These deductions agree with Greaves' reports (6, 7) that arsenic can in some manner liberate phosphorus from its insoluble compounds, and that arsenic stimulates bacterial action, thereby increasing crop yields.

SUMMARY

The effect of different calcium arsenate treatments upon five important soils was determined by measuring the yields of cotton from these soils. The yields on four of the soils, Houston clay loam, Memphis silt loam, Sarpy silty clay loam, and Sarpy fine sandy loam, were unaffected even from an application of 1,600 pounds of calcium arsenate per acre. However, the yield of cotton on Ruston sandy loam was greatly affected. A beneficial effect was obtained from the light applications and a detrimental effect from the heavy applications of calcium arsenate. However, the arsenic toxicity was reduced with time. The beneficial effect was attributed to three causes, namely, the applied calcium acting as a nutrient, the arsenic liberating insoluble phosphorus, and the calcium arsenate stimulating bacterial action.

The ability of the unaffected soils to render arsenic insoluble was probably due to their high pH and high colloidal content.

The soils used in this study are representative of many in the cotton belt, and the results obtained from them indicate that on these soils there is very little danger of reducing cotton yields with calcium arsenate. Since the average yearly application to cotton is hardly ever more than 30 pounds per acre and since much of it is lost every year, accumulation in the soils studied will probably never be great enough to inhibit cotton production.

LITERATURE CITED

1. Boyoucos, G. J. Directions for making analyses of soils by the hydrometer method. Soil Science, 43:225–228. 1936.
2. Cooper, H. P., Paden, W. R., Hall, E. E., Albert, W. B., Rogers, W. B., and Riley, J. A. The effect of calcium arsenate on the productivity of certain soil types, Forty-fourth Annual Report of the S. C. Agr. Exp. Sta. Ann. Rpt., 44:28. 1931.
3. ———, ———, ———, ———, ———, ———. Soils differ markedly in their response to additions of calcium arsenate. S. C. Agr. Exp. Sta. Ann. Rpt., 45:23. 1932.
4. Craft, A. S. Hilgardia, 9:461–498. 1935.
5. Greaves, J. E. The arsenic content of soils. Soil Science, 38:355–361. 1934.

6. ————. The stimulating influence of arsenic upon the nitrogen-fixing organisms of the soil. Jour. Agr. Res., 6:389–416. 1916.
7. ————. The influence of arsenic on the bacterial activities of a soil. Science Monthly, 5:204–209. 1917.
8. Reed, J. F., and Sturgis, M. B. Toxicity from arsenic to rice on flooded soils. Jour. Amer. Soc. Agron., 28:432–436. 1936.
9. Truog, Emil. The determination of rêadily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.

SOME EFFECTS OF CONTOUR LISTING ON NATIVE GRASS PASTURES[1]

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RECENT trends in range improvement have been toward increasing the cover of palatable forage plants through the utilization of a larger portion of the rainfall. Within large areas of the semiarid west it appears desirable to retain all of the rainfall, since range plants, especially the grasses, have the ability to use large amounts of water in the production of forage.

Most of the soils of the region are relatively deep and porous and provide ample storage space within the root zone for a large portion of the rainfall. On grassland with sparse vegetative cover, however, it is often expedient to use some kind of obstruction to check the movement of water, since the length of time that water is held on the land, as well as the infiltration rate of the soil type, determines to a large extent the amount that penetrates into the soil. Thus, the chief aim of mechanical structures is to retard the flow and give equal distribution of water over an entire area.

Studies were initiated at the Spur Substation in 1932 to obtain information on the effectiveness of contour listing of grassland in increasing vegetative cover and yield of forage. The increased production of grass resulting from this treatment was so striking that additional areas were listed in 1934 and in later years. The data on yields, basal cover, and moisture penetration from these studies are reported in this paper.

EXPERIMENTAL AREA

The native vegetation on the experimental area is characteristic of the short-grass (Buchloe-Bouteloua) pastures of the region. Before listing treatments were begun, it consisted largely of open mat type of buffalo grass (*Buchloe dactyloides*), with small amounts of blue grama (*Bouteloua gracilis*), purple three awn (*Aristida purpurea* and *A. Roemeriana*), and traces of many other grass species. Some of the more important weeds occurring on the area were broomweed (*Gutierrezia dracunculoides*), Indian wheat (*Plantago Purshii* and *P. spinulosa*), bitterweed (*Actinea odorata*), and peppergrass (*Lepidium densiflorum*). Small amounts of cacti and Yucca species were also present. The area supported in addition a rather heavy growth of mesquite brush (*Prosopis chilensis*) and a few plants of lote bush (*Condalia obtusifolia*). These shrubs were removed by grubbing as they were competing with desirable pasture plants.

The soil on which these studies were made is Miles clay loam, with a slope of 1 3%. Some sheet erosion has occurred on the steeper slopes and small gravel are present at the surface; however, there is no evidence of gully formation. Locally

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[1]Contribution from the Texas Agricultural Experiment Station, Spur, Texas, in cooperation with the Soil Conservation Service, U. S. Dept. of Agriculture. Received for publication September 15, 1939.

[2]Agronomist and Assistant Soil Conservationist, respectively. The writers gratefully acknowledge the suggestions and assistance of Mr. R. E. Dickson, Superintendent of Texas Substation No. 7, in outlining and conducting the work and in preparing the manuscript.

this soil is referred to as "tight" or "droughty" and is not well adapted to the production of cultivated crops.

PROCEDURE

Plats of approximately 1 acre were solid listed on contours to a depth of 3 inches during the spring of 1932, 1934, 1936, and 1938. Comparable adjoining plats were given no treatment. A two-row tractor lister with bottoms set 39 inches apart was used in the listing operation.

In order to protect representative samples of the vegetation from grazing animals, five screens, the framework of which were constructed of 2-inch by 4-inch lumber and covered with 2-inch wire netting, were located on each plat. The screens covered an area of 4 feet by 6 feet and were placed 12 inches above the ground level.

Harvests for yield comparisons on the areas thus protected were made when the grass reached maturity or when plants became dormant because of drought Two or three harvests were made yearly, the number depending largely on vegetative growth as influenced by the amount and distribution of rainfall. The vegetation was clipped to simulate close grazing, and green and air-dry weights of grass and weeds obtained. New sites for obtaining yield data on the plats were selected each year to avoid cumulative effects of protection from grazing.

Soil moisture samples were taken monthly during the growing season at each protecting screen to determine the effect of listing on the amount of available moisture and depth of penetration. Samples were taken at 1-foot levels to a depth of 6 feet with a 1-inch diameter soil tube, and dried to constant weight in an oven at 110° C.

Measurements of basal cover were made on meter quadrats on each plat during the growing season. The pantograph-chart method was used since it is well adapted for use in a study of the short grasses and open sod type of the other grasses (4).[3] The percentage of basal cover and percentage of total cover occupied by each species were determined from the charts by means of a planimeter.

In making determinations of root volume and weight, a column of soil 15 inches square and 66 inches deep was removed in 6-inch layers, and the roots carefully removed from the blocks by washing the mass over a fine screen with a spray of water, after the method described by Weaver and Harmon (5). The determinations of volume were made while the roots were water soaked, but excess water was removed from the root surfaces with blotters

EXPERIMENTAL RESULTS

YIELD OF NATIVE VEGETATION

The rapidity with which grass becomes re-established after listing depends largely upon the abundance of those species which have the ability to reproduce vegetatively. Buffalo grass, under only moderately favorable conditions, rapidly increases vegetatively by means of stolons. The upper part of Fig. 1 shows a plat of buffalo grass just after it was listed in 1936. The berm left on each side of the furrows provides sufficient grass to vegetate completely the furrows and ridges in a favorable season. The lower part of Fig. 1 shows the same plat in 1937 at the end of the second growing season after listing.

[3]Figures in parenthesis refer to "Literature Cited", p. 981.

Yields from listed and unlisted plats are presented in Table 1. No yields are reported from the 1932 listing for the reason that differences in soil type preclude a comparison of the 1932 yields with those obtained from treatments made in other years. During the period of 1935 to 1938 an average yield of 630 pounds of air-dry grass per acre

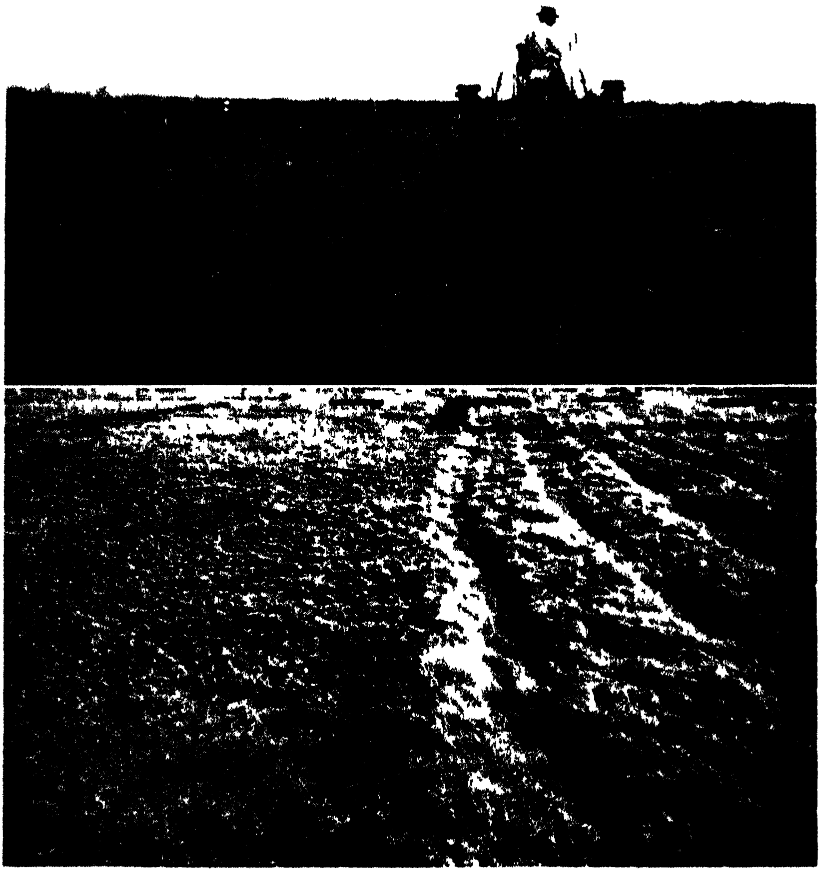

FIG 1 —*Upper*, plat of native pasture following listing in 1936. *Lower*, same plat at the end of the growing season in 1937

was made by the unlisted areas as compared with 1,812 pounds from the area listed in 1934. Comparable averages for shorter periods, including results from listing treatments made in later years, show that grass production was increased 2.3 to 3.9 times by listing. The highest annual yield from any one treatment, 2,424 pounds of grass per acre, was obtained in 1935 from the 1934 listing.

Yields from the plats the first year following spring listing have been consistently greater than from those not listed. The amount of

grass cover destroyed during the early part of the season, as evidenced in Fig. 1, was compensated for by increased vigor, greater height, and prolonged growing season of the vegetation. In the early years of the study the increase from listing was attributed largely to the conserving of the rainfall (3), but numerous field observations made through the years indicate that some of the increase may have been caused by the cultivation or loosening of the soil. Studies which have as their objective the isolation of some of the factors involved in this phase of the problem are now under way.

In 1935 and 1936 weeds occurred only in trace amounts and no distinction was made between grass and weeds in reporting yields for these years. Increased weed growth in 1937 and 1938, however, justified weighing and reporting grass and weeds separately. Data in Table 1 show that growth of weeds, mostly annuals, may increase the first year after listing, but these usually disappear as the furrows and ridges become vegetated with grasses. After a period of years weeds have practically disappeared on listed areas.

TABLE 1.—*Acre yields in pounds of air dry grass and weeds from contour listed and unlisted grassland, 1935–1938.*

Treatment	1935 grass	1936 grass	1937, Grass	1937, Weeds
Unlisted	858	592	259	30
Listed 1934	2,424	2,315	1,133	76
Listed 1936		1,326	2,159	185
Listed 1938		—	—	—

Treatment	1938 Grass	1938 Weeds	1935–38 av grass	1936–38, av grass	1937–38 Grass	1937–38 Weeds
Unlisted	810	403	630	554	534	216
Listed 1934	1,376	107	1,812	1,608	1,254	92
Listed 1936	1,973	231	—	1,819	2,066	208
Listed 1938	1,178	491	—	—	—	—

SOIL MOISTURE CONTENT

In order to minimize the effect of any existing variation in soil type, the moisture data are expressed in inches of available water rather than as a percentage relationship of total water to dry soil. Accordingly, moisture samples were taken during the growing season when it was evident that the water available to plants had been consumed and the vegetation was dormant. The average moisture under these conditions is the amount not available to plants. This degree of moisture depletion has been termed the "minimum point of exhaustion" (2). The so-called available water is obtained by deducting the minimum point of exhaustion from the total moisture.

The value of listing as a water conserving practice is revealed in the increase of available moisture and depth of penetration (Table 2).

The average available moisture in 1937 and 1938 to a depth of 6 feet was 1.32 inch on the unlisted areas. Of this amount, 76.52% was present in the upper 2 feet, while only 23.48% was stored in the lower 4 feet. On grassland that was listed in 1934, 3.12 inches of available water was stored in the soil. The upper 2 feet contained 50.64% of the moisture and the lower 4 feet contained 49.36%. A similar increase in the supply of available moisture and in penetration was obtained on land listed in 1936.

TABLE 2.—*Annual and average quantities of available water in the surface 6 feet of the soil during the growing season and percentage distribution at different depths, 1937-38.*

Depth of sampling, feet	Average amount of available water in the soil during the growing season, inches			Percentage of average available moisture		
	1937	1938	Average	Each foot	Upper 2 feet	Lower 4 feet
			Unlisted			
1	0.86	0.59	0.72	54.55	76.52	23.48
2	0.39	0.19	0.29	21.97	—	—
3	0.04	0.08	0.06	4.54	—	—
4	0.00	0.03	0.02	1.52	—	—
5	0.12	0.19	0.16	12.12	—	—
6	0 00	0.14	0.07	5.30	—	—
Total	1.41	1.22	1.32			
			Listed, 1934			
1	1.17	0.77	0.97	31.09	50.64	49.36
2	0.78	0.44	0.61	19.55	—	—
3	0.62	0.42	0.52	16.67	—	—
4	0.53	0.26	0.40	12.82	—	—
5	0.56	0.16	0.36	11.54	—	—
6	0.41	0.11	0.26	8.33	—	—
Total	4.07	2.16	3.12			
			Listed, 1936			
1	1.17	0.69	0.93	27.27	46.63	53.37
2	0.81	0.50	0.66	19.35	—	—
3	0.78	0.54	0.66	19.35	—	—
4	0.68	0.37	0.52	15.25	—	—
5	0.39	0.17	0.28	8.21	—	—
6	0.56	0.15	0.36	10.56	—	—
Total	4.39	2.42	3.41			
			Listed, 1938			
1	—	0.75	—	32.19	61.37	38.63
2	—	0.63	—	29.18	—	—
3	—	0.37	—	15.88	—	—
4	—	0.32	—	13.73	—	—
5	—	0.21	—	9.01	—	—
6	—	0.00	—	0.00	—	—
Total		2.33				

On numerous occasions following heavy rain periods noticeably increased moisture penetration occurred on the listed pasture areas. Determinations made before and soon after a heavy rain period in 1936 showed that the average moisture penetration was to a depth of 72 inches on the listed plats as compared to 30 inches on the unlisted, and the amount of available moisture stored was 6.67 and 2.10 inches, respectively.

Measurements made at the end of the 1938 growing season show that the following amounts of rain falling on each listed area would be retained in the furrows without allowing for any penetration: 1932 listing, 0.80 inch; 1934 listing, 0.84 inch; 1936 listing, 0.95 inch; 1938 listing, 1.03 inch. Although the furrows form only a small reservoir, the combined effect of a high infiltration rate and the furrows' serving as a catchment basin is to increase materially the opportunity for the penetration of large amounts of water. It is evident that with the passing of time the retentive capacity of the furrows is somewhat reduced by slowly filling in with soil.

BASAL COVER AND COMPOSITION OF COVER

A distinct change occurred in the basal cover and composition of native vegetation following listings made in 1932 and 1934. To obtain definite information regarding those changes, 5-meter quadrats were located at representative points on each plat and charted in 1937 and 1938. The basal cover represents that portion of the soil surface covered by living plants. Where plant parts were less than 1 cm distant, the area was considered as being fully covered.

The most outstanding change in cover was the increase in buffalo grass following listing treatments. The average basal cover of this grass in 1937 and 1938 was 14.02% on unlisted grassland and 64.96% on grassland listed in 1934 (Table 3). Similar increases in cover of buffalo grass were obtained from the treatments made in 1936 and 1938. It is also of interest that only 44.96% of the total cover of the vegetation on the unlisted grassland was buffalo grass, as compared to 87.04% on the area listed in 1934, 82.07% on the area listed in 1936, and 85.23% on that listed in 1938.

Listing has brought about only minor changes in the basal cover of the other grasses. Little barley (*Hordeum pusillum*) appears to increase the first year following listing but is gradually replaced by perennial grasses. The cover of purple three awn, which has a low palatability to most classes of livestock, seems to decrease gradually over a period of years after listing. Grassland that was listed in 1932 and 1934 shows a reduction in cover of purple three awn, while the cover of this species on grassland listed in 1936 has remained practically the same. In all cases, however, the percentage of cover provided by purple three awn in comparison to the total vegetative cover has been reduced by listing.

The basal cover of all weed species, especially that of Indian wheat, peppergrass, and bitterweed, has been appreciably reduced by listing. The marked reduction of bitterweed is of particular importance to stockmen, since this plant is poisonous to sheep. Dameron and Cory

TABLE 3.—*Average percentage, 1937 and 1938, of basal cover and total cover of native vegetation on contour listed and unlisted grassland.*

Species	Common name	Unlisted		Listed, 1934		Listed, 1936		Listed, 1938*	
		Basal cover	Total cover	Basal cover	Total cover	Basal cover	Total cover	Basal cover	Total cover
Grasses:		21.46	68.83	70.28	94.17	75.60	93.16	48.30	91.60
Buchloe dactyloides	Buffalo grass	14.02	44.96	64.96	87.04	66.60	82.07	44.94	85.23
Bouteloua gracilis	Blue grama	0.78	2.50	2.18	2.92	1.41	1.74	0.60	1.14
Aristida purpurea and *A. Roemeriana*	Purple three awn	4.23	13.57	1.62	2.17	4.74	5.84	1.84	3.49
Hordeum pusillum	Little barley	0.80	2.57	0.56	0.75	2.24	2.76	—	—
Schedonnardus paniculatus	Tumblegrass	0.96	3.08	0.52	0.70	0.20	0.25	0.60	1.14
Others		0.67	2.15	0.44	0.59	0.41	0.51	0.32	0.61
Weeds:		5.41	17.35	2.60	3.48	3.13	3.86	4.43	8.40
Plantago spinulosa and *P. Purshii*	Indian wheat	3.46	11.10	1.62	2.17	1.34	1.65	—	—
Ledpidium densiflorum	Pepper grass	1.16	3.72	0.08	0.11	0.38	0.47	—	—
Verbena bipinnatitida	Wild verbena	Trace	Trace	0.04	0.05	Trace	Trace	—	—
Others		0.79	2.53	0.86	1.15	1.41	1.74	4.43	8.40
Undesirable weeds:		4.31	13.82	1.75	2.34	2.42	2.98	—	—
Actinea odorata	Bitterweed	3.82	12.25	0.17	0.23	0.47	0.58	—	—
Senecio longilobus	Threadleaf grounsel	0.15	0.48	0.94	1.26	0.41	0.51	—	—
Others		0.34	1.09	0.64	0.86	1.54	1.90	—	—
Total basal cover, %		31.18	—	74.63	—	81.15	—	52.73	—
Unprotected soil, %		68.82	—	25.37	—	18.85	—	47.27	—

*Two quadrats.

(1) also have found that the cover of bitterweed is reduced as the cover of turf grasses increases.

UNDERGROUND PLANT MATERIALS

Determinations of root volume and weight were made at two locations selected at random on an unlisted area and on the area listed in 1934. Roots are reported by weight on oven-dry basis and by volume in cubic centimeters of water displaced (Table 4). The root system was 63.63% greater in volume and 78.91% greater in dry weight from the listed than from the unlisted plat. Likewise, the maximum penetration of roots was to a depth of 66 inches and 44 inches on the two plats, respectively.

TABLE 4.—*Volume and weight of underground plant materials from contour listed and unlisted grassland, 1936.*

Depth, inches	Water displaced, cc		Oven-dry material, grams	
	Listed*	Unlisted	Listed*	Unlisted
1–6	464	259	95.14	45.14
8–14	60	56	11.33	10.49
16–22	27	25	7.19	7.03
24–30	15	13	3.87	3.78
34–40	12	10	1.96	1.34
42–48	9	Trace	1.38	0.11
50–56	6	0	0.52	0.0
60–66	1	0	0.07	0.0
Total	594	363	121.46	67.89
Increase, %	63.63		78.91	

*In 1934.

A visual representation of the amount of roots found at different depths is shown in Fig. 2. The slightly darker shade of color of the roots from the unlisted plat is the result of the large number of dead roots found in the mass. Since roots exist in the soil in all stages of decomposition, it is not to be expected that all of the underground materials are living; however, at every depth the unlisted land has a much higher proportion of dead materials than that which was listed. The roots from the listed plat were relatively free from dead materials and for the most part appeared to be in a vigorous growing condition.

TABLE 5.—*Amount and ratio of oven-dry plant materials from contour listed and unlisted grassland, 1936.*

Treatment	Oven-dry materials per acre, tops			Ratio of tops to roots
	Dry grass	Roots*	Total	
Listed in 1934	1.066	3.732	4.798	1:3.50
Unlisted	0.327	2.086	2.413	1:6.38

*Depth, 66 inches.

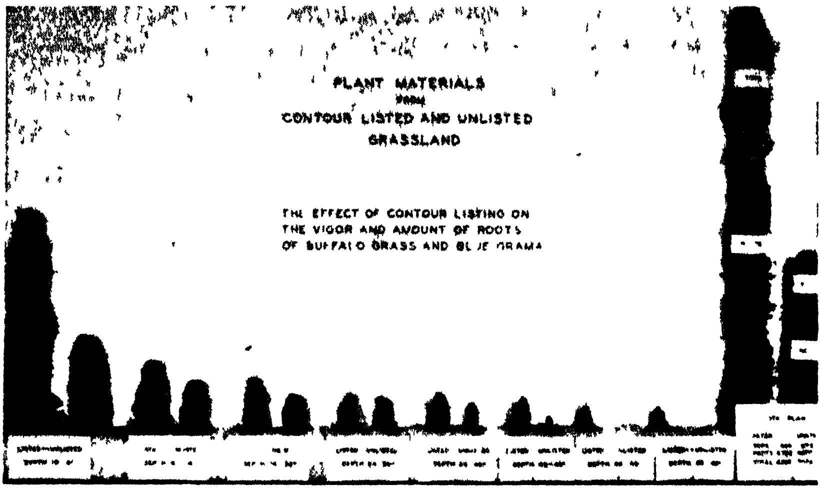

FIG 2 —From left to right in pairs, roots of buffalo and blue grama grass that were removed at intervals of 6 inches to a depth of 66 inches from listed and unlisted areas At extreme right, total roots and tops from listed and unlisted areas, roots removed to depth of 66 inches

The amount of plant materials and the ratio of roots to tops are shown in Table 5 The weight of roots from either of the treatments far exceed the weight of forage. The ratio of tops to roots on listed and unlisted plats is 1:3.50 and 1:6.38, respectively In the case of the unlisted plat the ratio of tops to roots is wide, probably because of the larger proportion of dead roots present.

SUMMARY

Grassland with a cover consisting primarily of buffalo grass was solid listed on contours to a depth of 3 inches with the following results:

1. Yields of grass were increased as much as 3.9 times, the highest annual yield from any one treatment being 2,424 pounds of air-dry grass per acre.
2. Increases in available soil moisture and depth of penetration were reflected in higher yields of grass, greater basal cover, and the tendency of the listed areas to remain green longer during periods of deficient rainfall
3. The most important vegetal change was the large increase in cover of buffalo grass, which was accompanied by a marked decrease in cover of weeds and area of bare soil.
4. A greater volume and deeper penetration of roots occurred on listed grassland. A high percentage of roots on unlisted grassland appeared to be dead, while those from the listed area were in a vigorous growing condition.

LITERATURE CITED

1. DAMERON, W. H., and CORY, V. L. Bitterweed control. Tex. Agr. Exp. Sta. Ann. Rpt., 1936:270. 1936.
2. HALLSTED, A. L., and MATHEWS, O. R. Soil moisture and winter wheat with suggestions on abandonment. Kan. Agr. Exp. Sta. Bul. 273. 1936.
3. LANGLEY, B. C. Rejuvenating native grass pastures. Soil Conservation, 11:1–2. 1936.
4. SAVAGE, D. A., and JACOBSON, L. A. The killing effect of heat and drought on buffalo grass and blue grama grass at Hays, Kansas. Jour. Amer. Soc. Agron., 27:566–582. 1935.
5. WEAVER, J. E., and HARMON, GEORGE W. Quantity of living plant material in prairie soils in relation to run-off and soil erosion. Cons. and Surv. Div. Univ. Nebr., 8:1–53. 1935.

HARMFUL ROOT INTERACTIONS AS A POSSIBLE EXPLANATION FOR EFFECTS NOTED BETWEEN VARIOUS SPECIES OF GRASSES AND LEGUMES[1]

H. L. Ahlgren and O. S. Aamodt[2]

MANY species of plants and more particularly those used for hay or pasture purposes are sown in mixtures. Dominance of any given species in any particular environment has usually been attributed to differential moisture, temperature, light, and fertility requirements. Investigations have shown that the development and activity of the roots of certain species of plants may be affected by the metabolism of adjoining roots and that some species of plants may have a specific effect on other species which follow in the rotation. An excellent review of the literature on this subject has been made by Loehwing.[3] There is considerable difference of opinion in the literature as to the cause of specific interactions which have been noted. Toxic secretions, deficient oxygen, excessive carbon dioxide and moisture, harmful pH, and nitrogen starvation are among the more important factors listed as being involved in specific root interactions.

It is the purpose of this preliminary report to call attention to the possible existence of harmful root interactions between various species of pasture grasses and legumes and the need for further investigations relative to the extent and importance of this phenomenon under varying light, moisture, temperature, and fertility conditions.

Extensive botanical studies relative to the effect of various fertilization and management treatments on the productivity and survival of a number of species of plants used for hay and pasture purposes were begun at the University of Wisconsin in 1935. Included among the species studied were Kentucky bluegrass (*Poa pratensis*), timothy (*Phleum pratense*), redtop (*Agrostis alba*), red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*), and white clover (*Trifolium repens*). Field observations made since the experiment was initiated seemed to indicate that a number of species interactions occurred which could not be accounted for on the basis of differential response to light, temperature, moisture, fertilization, and management. White clover and red clover were seldom found in dense, closely grazed quack grass (*Agropyron repens*) sod whereas alsike clover appeared in comparative abundance. Canada bluegrass (*Poa compressa*), although not seeded, was found in areas which were not fertilized with commercial nitrogen. Canada bluegrass, redtop, timothy, and Kentucky bluegrass were observed to occur as definite colonies rather than blending uniformly throughout the sward. Redtop was eliminated early by Kentucky bluegrass.

In August of 1938 a series of experimental pasture and meadow field plats were sown to compare the yield and survival of two strains of brome grass (*Bromus inermis*), both commercial and parkland,

[1]Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication September 17, 1939.

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[3]Loehwing, W. F. Root interactions of plants. Bot. Rev., 3:195–239. 1937.

timothy, and Kentucky bluegrass under various soil treatments and management programs. One of the variables consisted of a mixture of red, white, and alsike clovers sown across the grass plats which were replicated six times. All of the plats had perfect stands of grasses and legumes in the fall before growth was stopped by low temperatures. A mild winter followed, although there was little snow cover.

After growth of the plants started in the spring of 1939 it was soon evident that a very marked differential interaction had taken place between the clovers and *one* of the grasses. The stands of the two strains of brome grass and timothy were uniformly good on all the plats regardless of treatment or association with legumes. The Kentucky bluegrass, however, was practically eliminated from that portion of each plat on which the clovers were growing in association with the grass. The other three grasses were not in any way affected by the legumes. There appeared to be no other probable explanation of the striking apparent interaction between the clovers and the Kentucky bluegrass in this experiment.

In order to obtain more specific data on these apparent interactions, preliminary studies were begun under controlled conditions in the greenhouse in an attempt to determine if measurable effects could be obtained between various associations of Kentucky bluegrass, Canada bluegrass, redtop, and timothy.

Seedling plants of Kentucky bluegrass, redtop, timothy, and Canada bluegrass were transplanted to non-sterilized soil (¾ Carrington silt loam and ¼ sand) in greenhouse benches on October 25, 1938. Pure culture plats of Kentucky bluegrass, timothy, redtop, and Canada bluegrass were established. Three rows of 16 plants each with plants spaced 2 inches apart constituted a plat. Each plat was duplicated and separated by a 6-inch border from the adjacent plats. In addition to the pure cultures, combinations were used of (a) Kentucky bluegrass and redtop, (b) timothy and redtop, and (c) Canada bluegrass and Kentucky bluegrass. The plan of procedure in the case of the combinations was similar to that used in the pure cultures excepting that individual plants of each species being studied were alternated in each row. The temperature in the greenhouse was maintained at 60° to 65° F during the experiment

The root and top growth produced by the various species growing in pure culture and in combinations was determined from five random plants of each species selected from the center row of each duplicate plat. Plants at the end of the row were not used. After each harvest all of the remaining plants were cut back to soil level. Cuttings to determine the amount of foliage produced by plants growing on the various plats were made on January 30 and on March 14, 1939. The roots were removed from the soil on March 18, washed, and the weight on an oven-dry basis determined.

The data obtained in the study were analyzed according to Fisher's analysis of variance and are given in Tables 1 and 2. The calculated minimum difference at the 5% point for yield of foliage was found to be 0.44 gram. From a study of the data it is apparent that a number of significant species interactions occurred. The average weight of

dry matter in the foliage of each plant of Canada bluegrass was 0.26 gram when grown in combination with Kentucky bluegrass, and 0.45 gram when grown in pure culture. The average weight of foliage per plant of timothy was 0.36 gram when grown in combination with redtop and 0.58 gram when grown in pure culture. Likewise, the average weight of the foliage produced per plant of Kentucky bluegrass was 0.195 gram when grown with redtop and 0.343 gram in pure culture. The yield of redtop was lower when grown in combination with timothy and Kentucky bluegrass, but the reduction was not great enough to be statistically significant. The yield of Kentucky bluegrass was also lower, though not significantly so, when grown with Canada bluegrass.

TABLE 1.—*Average dry weight per plant of the foliage of Kentucky bluegrass, Canada bluegrass, redtop, and timothy grown in pure culture and in various coombinations.*

Species	Average weight per plant in grams*
Pure Cultures	
Redtop	0.369
Kentucky bluegrass	0.343
Canada bluegrass	0.450
Timothy	0.577
Timothy and Redtop	
Timothy	0.360
Redtop	0.294
Kentucky Bluegrass and Redtop	
Kentucky bluegrass	0.195
Redtop	0.311
Canada Bluegrass and Kentucky Bluegrass	
Canada bluegrass	0.260
Kentucky bluegrass	0.264

*Each figure recorded represents the average weight per plant of 20 individual plants. Minimum difference required for significance at the 5% point = 0.44 gram.

The average weight of roots produced per plant by each of the species studied is given in Table 2. The calculated difference required for significance at the 5% point in the case of root production was found to be 0.11 gram per plant. The average weight of dry matter in the harvested roots of each plant of timothy was 0.221 gram when grown in combination with redtop and 0.339 gram when grown in pure culture. The average weight of the roots of each plant of Canada bluegrass was 0.137 gram when grown in a combination which included Kentucky bluegrass and 0.287 gram when grown in pure culture. In all other cases the roots of the plants grown in combinations was reduced, although differences were not great enough to be statistically significant.

The data presented would appear to indicate that harmful root interactions may occur between various species of pasture grasses

TABLE 2.—*Average dry weight per plant of the roots of Kentucky bluegrass, Canada bluegrass, redtop, and timothy grown in pure culture and in various combinations.*

Species	Average weight of roots per plant in grams*
Pure Cultures	
Redtop	0.244
Kentucky bluegrass	0.199
Canada bluegrass	0.287
Timothy	0.339
Timothy and Redtop	
Timothy	0.221
Redtop	0.184
Kentucky Bluegrass and Redtop	
Kentucky bluegrass	0.151
Redtop	0.222
Canada Bluegrass and Kentucky Bluegrass	
Canada bluegrass	0.148
Kentucky bluegrass	0.137

*Each figure recorded represents the average weight per plant of the roots of 20 individual plants. Minimum difference required for significance at the 5% point = 0.110 gram.

and legumes. These interactions are no doubt profoundly influenced by environmental conditions. Their full significance will not be known until they have been tested under various light, fertility, and management conditions. There is need for intensive fundamental study relative to the nature of these interactions and their effect on grass and legume species now commonly used in pasture and meadow mixtures.

NOTE

A SOIL MOISTURE TENSIOMETER WITH A COMPACT MANOMETER[1]

RECENT experiments have shown that a vacuum gauge, when attached to a porous cell which is filled with water and buried in soil, provides a convenient indication of the condition of the moisture in the soil. Such a device, of course, will operate successfully only over a soil moisture tension range somewhat less than 1 atmosphere. For greenhouse pot experiments, however, there is indication that the moisture condition for optimum growth lies well within this range.

The compact form of manometer shown in Fig. 1 has been used on tensiometers installed in greenhouse pots to aid in determining when water is needed, and the amount to be applied. Making the manometer is a relatively simple glass blowing operation. The range and accuracy desired in the measurements will determine the dimensions of the various parts. The relation of the manometer reading x, in cm, to the tension in the cup water t, in cm of mercury, is indicated by the formulae

$$(v_1+la+v_2)\left(Po-\frac{12.5}{13.5}h_2+h_3\right)=nRT \qquad (1)$$

$$(v_1+xa)\ (B-t+x)\left(1+\frac{12.5}{13.5}\frac{a}{A}\right)+h_1-\frac{12.5}{13.5}\left(+h_2+\frac{h_4}{12.5}+\frac{v_2}{A}+\frac{la}{A}\right)=nRT \qquad (2)$$

These equations are simply the gas law expressions for the volume and pressure of the air in the closed arm as related to the barometric pressure B and the absolute temperature T. The symbols h_1, h_2, h_3, and h_4 represent the distances from these several points to the top of the air trap. The cross sectional areas of the closed and open arms of the manometer are, respectively, a and A and l is the length of the capillary section.

During operation the air in the closed arm has a pressure less than that of the atmosphere. To accomplish this, the side arm c is filled with dry mercury and then, after filling the porous cell with water, a vacuum pressure Po is applied at the air trap. During this air removal process the mercury stands at the dotted levels h_2 and h_3, and v_1 and v_2 are, respectively, the volumes of the closed arm above and belo · the capillary. In general it is desirable that Po be of the order of a ..nth of an atmosphere or less so that high tensions will not change the zero setting. The constants nR in equation (2) may be eliminated by use of equation (1).

A linear scale may be attached to the closed arm. Alternatively it has been found convenient to place several colored lacquer marks on the capillary tubes, corresponding to several known tensions. This calibration should be made from an open tube manometer attached to the air trap at the time of the zero setting. The effect of a change

[1]Journal paper No. J-673 of the Iowa Agricultural Experiment Station, Ames, Iowa. Projects 308 and 504.

in the atmospheric pressure or temperature on the tension indicated by the closed tube manometer may be calculated from equation (2). The manometers used in the pot experiments here reported were like the one shown in the scale drawing; for the use here described atmospheric pressure and temperature effects on the manometer reading may be neglected. The porous cups used were made by the General Ceramics Company, Refractories Division, 30 Rockefeller Plaza, New York, N. Y., cup No. K948.[2]

Thirty-eight hundred grams of soil were weighed into each of nine 1-gallon stoneware pots. Tensiometers were placed in each pot, midway between the side and center and at a depth which left 1 inch of soil below the bottom of the porous cell. Corn was planted and later thinned to four plants per pot. After the plants had reached a height of about 4 inches, three moisture levels--dry, intermediate, and wet—were established, each level being replicated three times. In the dry series water was withheld until the plants began to wilt, after which the tension was reduced to 50 cm of Hg by surface applications of water. In the intermediate series the tension was held between 30 and 50 cm and in the wet series between 0 and 30 cm.

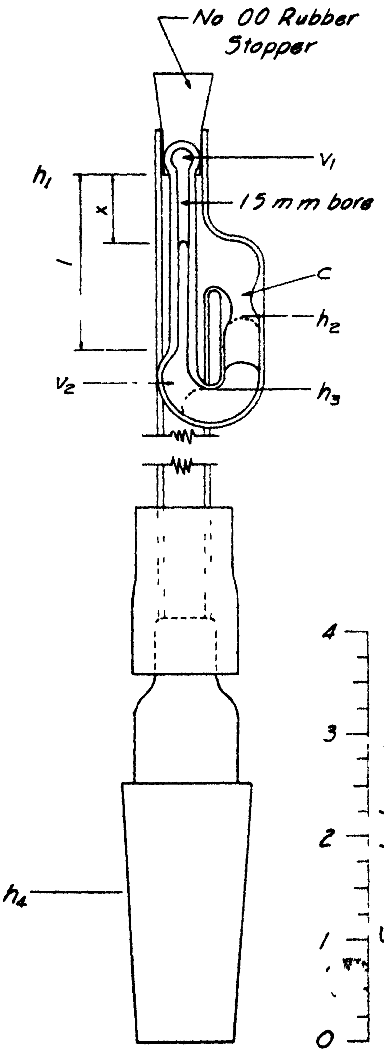

FIG. 1.—Type of manometer used.

After 52 days the plants were harvested and weighed. Table 1 gives the green weight, percentage moisture, and dry weight of the plants from each pot. The moisture content increased slightly with increased water supply as would be expected. The variation in plant growth within and between the treatments, measured by weight, may be taken as an indication of the accuracy of moisture control.

[2]RICHARDS, L. A., RUSSELL, M. B., and NEAL, O. R. Further developments on apparatus for field moisture studies. Soil Sci. Soc. Amer. Proc., 2:55. 1937.

TABLE 1.—*Weight and percentage moisture of plant tissue produced at three levels of water supply.*

Pot No.	Wet series			Intermediate series			Dry series		
	Wet weight, grams	% moisture	Dry weight, grams	Wet weight, grams	% moisture	Dry weight, grams	Wet weight, grams	% moisture	Dry weight, grams
1	43.27	86.5	5.83	25.11	85.1	3.74	17.98	83.0	3.05
2	33.20	85 8	4.70	24.25	85.2	3.59	13.91	85.2	2.06
3	37.91	85 4	5.52	25.98	84.6	3.99	23 17	83 6	3.80
Average	38.12	86.6	5.35	25.11	85 0	3.44	18.35	83 9	2.97

The larger variation between checks in the dry series shows that at this low level the moisture was not regulated as closely as in the intermediate or wet series. In the intermediate series the moisture level was controlled more closely, as shown by the smaller variation between replications. Since intermediate moisture levels are desirable in most greenhouse work, the use of tensiometers for indicating time of irrigation and amounts of water to apply should prove satisfactory.

The distribution of moisture in the soils after harvest is given in Table 2. The pots had not been watered for 24 hours before samples were taken for moisture determinations. Composite samples from each series were used. The roots in the wet series were concentrated in the lower part of the soil, accounting for the lower moisture content in this region. In the intermediate series the roots were rather well distributed through the soil, with some tendency toward concentration in the lower part. In the dry series the roots were well distributed with some concentration both near the surface and in the lower part of the soil.

TABLE 2.—*Distribution of moisture in soils and average moisture content at time of harvest.*

Portion of soil	Wet series	Intermediate series	Dry series
Top ⅓	32.10	18.12	14.95
Center ⅓	33.05	19.20	15.88
Lower ⅓..	24.08	17.61	16.36
Average	29.74	18.31	15.73

The moisture equivalent of the soil was found to be 28.7, which would indicate a wilting coefficient of about 15.6. The moisture content of the soils as determined should be the lower limit for each treatment, since the tensiometers indicated need for irrigation at the time of sampling. Thus, the lower limit for the dry series was very near the wilting point; in the intermediate series it was about 2.6% higher, and in the wet series it was very slightly above the moisture equivalent.

To change the reading of a tensiometer requires a transfer of water between cup and soil. Because of the low rate of moisture movement

in relatively dry soils (tensions above 50 cm of mercury), tensiometers will not reliably indicate soil moisture tension at any appreciable distance from the cup. This is especially true in the case of large tension gradients, as when plant root systems are in the neighborhood of the cup. It is rather unlikely after starting the moisture control in the dry series that soil moisture was ever uniformly distributed. The concentration of roots near the surface indicates that probably most of the moisture absorption took place in this region. With daily examination, the dry series was irrigated whenever wilting was observed, but the important thing to note is that only sufficient moisture was added to drop the tension of the soil moisture in the neighborhood of the porous cup to a minimum of 50 cm of mercury. It was occasionally necessary to refill the tensiometers in the dry series with water so as to remove accumulations of 2 or 3 cc of air, but no particular concentration of roots around the porous cups was observed in any of the pots.—L. A. RICHARDS and R. W. PEARSON, *Iowa State College, Ames, Iowa.*

BOOK REVIEWS

METHODS OF STATISTICAL ANALYSIS

By C. H. Goulden. New York: John Wiley and Sons. VII+277 pages, Illus. 1939. $3.50.

THIS work is the first printed form, revised and enlarged, of a bound mimeograph, two editions of which were issued. A review of the first mimeographed edition was published in this JOURNAL (vol. 28, page 772).

In the preface of the present volume, the author states, "The basis of this book, therefore, is the supplying of a textbook in statistics for students who have passed the elementary stage; who have studied a fair amount of theory and principles and now wish to equip themselves for actual statistical work in their own field of research activities." This statement excuses the author for only briefly considering the theory of statistics and for omitting discussion of experimental technic such as selection of test areas, eliminating border effects, planting, harvesting, etc. The reader is expected to have secured this groundwork previous to a study of this volume.

The book combines statistical mathematics, chiefly the phase usually called "small sample theory", with experimental design. About two-thirds of the book is devoted to the former and one-third to the latter subject, if we are guided by the contents of the usual books on these subjects. It must be admitted that both these phases are intermingled in many parts of the work. While the review of statistical mathematics is concise, well-balanced, and illustrated by numerous worked examples all of which reflect to the credit of the author, the reviewer believes that experimentalists, especially those concerned with field tests, will welcome especially the chapters dealing with experimental design because (1) a considerable amount of this subject matter is not found in other American works; (2) the author has brought together pertinent material, much of which is

scattered through the literature; (3) the selections have been carefully made; and (4) each type of design selected has been illustrated by an example carefully worked out and clearly expressed. Furthermore, the student who wishes to investigate the subject more fully will appreciate the references to the literature given at the end of each chapter.

The chapter headings include Calculation of the Arithmetic Mean and Standard Deviation—Frequency Tables and Their Preparation; Theoretical Frequency Distributions; The Design of Simple Experiments; Linear Regression; Correlation; Partial and Multiple Regression and Correlation; The X^2 (Chi-square) Test; Tests of Goodness of Fit and Independence with Small Samples; The Analysis of Variance; The Field Plot Test; The Analysis of Variance Applied to Linear Regression Formulae; Non-linear Regression; The Analysis of Covariance; and Miscellaneous Applications (includes the estimation of missing values and methods of randomization). Tables of *t*, Chi-square, and F and an index complete the volume.

Because of their importance, reference should be made to the subjects covered in the chapter entitled "The Field Plot Tests", *viz.*, General Principles and Standard Designs, including the sub-titles soil heterogeniety, replication, randomization, error control, randomized blocks, the Latin square, factorial experiments, split-plot experiments; Confounding in Factorial Experiments, including orthogonality and confounding, partial confounding and recovery of information, splitting up degrees of freedom into orthogonal components, confounding in a 3 x 3 x 3 experiment, partial confounding in a 3 x 3 x 3 experiment; and Methods for Testing a Large Number of Varieties, including incomplete block experiments, two-dimensional quasi-factorials with three groups of sets, three-dimensional quasi-factorials with three groups of sets, and symmetrical incomplete block experiments. The printing is excellent and the book is well bound. (F. Y. H.)

BOTANY

By William J. Robbins and Harold W. Rickett. New York: D. Van Nostrand Company. Ed. 3. XI+658 pages, illus. 1939 $3.75.

THIS edition follows closely the plan of the second edition. The subject matter has been brought more nearly up-to-date and many new illustrations have been included. In order to make the subject more interesting to the lay student the presentation starts out with a study of plant growth instead of a study of its cellular structure. The book was written for use of general students and is not intended as a foundation for professional botany. The elementary course in botany gives a clear understanding of biological principles to students who do not intend to go on with a study of biological sciences.

Part I deals with the living plant. A discourse on growth is followed with chapters on the structure, foods and nutrition responses, reproduction, heredity, and nature of life of plants. Part II, on the kinds of plants, gives a clear and concise discussion of the plant groups.

The student should become acquainted with the characteristic life cycles and importance of representatives of each group. Final chapters treat of the origin and evolution of life and the distribution of plants on the earth.

Questions for review and discussion along with references are given at the end of the book. These are designed to help test the student on his mastery of the subject.

The excellent manner in which the subject is presented cannot help but acquaint the student with the fundamental physiological process of living things along with their structure, and with the variety and extent of the plant kingdom. Fundamental principles of reproduction, inheritance, and evolution are presented in such a manner that a student should obtain a concise idea of the meaning of life as illustrated by the plant kingdom. (O. A. R.)

ELEMENTS OF STATISTICAL REASONING

By Alan E. Treloar. New York: John Wiley and Sons, Inc. XI+ 260 pages, illus. 1939. $3 25.

THE chapter headings of this book are Numerical Description; the Law of Frequency Distribution; Typical Values; the Measurement of Variation; Moments and Distribution Characteristics; the Normal Curve; Bivariate Distribution and the Coefficient of Correlation; Rectilinear Regression; Residual Variation; Errors of Random Sampling; Sampling Errors of the Correlation Coefficient; Proportions and Probability; the Proportions of Vital Statistics; Sampling Errors of Proportions; the Measurement of Frequency Discordance; and Independence and Bivariate Tables of Frequency. The Appendix includes a table of normal curve functions; tables of z as a function of r; a graph of probability levels for r when ρ is zero and N is small; a table of the probability integral of χ^2; and selected formulas. An index completes the volume. No bibliography is included.

Textbooks dealing with statistical methods vary much in the proportion devoted to explanation or logic of each phase of the subject and that used to show the methods of calculation. At one extreme are books in which very little descriptive matter is presented with most of the text given to algebra and arithmetic. In fact these might well be called computers handbooks. The majority of American works on statistics contain about equal amounts of descriptive matter and of computation. The present volume goes to the other extreme by making the logic of statistics the main theme, using worked examples to illustrate the theory discussed. Thus, the author follows the plan used by many British and European writers. His aim is to cultivate in the student, "a keen appreciation of the analytical power in quantative logic which a knowledge of mathematics may open to him." This viewpoint is epitomized in the preface where it is stated, "What is written herein is intended for those who wish to reason carefully, not merely imitate".

Dr. Treloar has written a logical, condensed book that carries out his aims for the phases of the subject selected and has produced a

work that should greatly assist all investigators who wish to make the best use of statistical methods in the interpretation of their results. Unfortunately, the author for reasons of economy has felt compelled to present only certain phases of the subject. Small sample statistics have been omitted entirely. Although the book is limited to large sample theory, a number of important subjects belonging to this group are not included, the most prominent being partial and multiple correlation. It is hoped that the reception of the present book will warrant the publishing of a second volume covering all these subjects.

The book is an excellent text for those who desire to secure an up-to-date foundation in large sample theory, although the beginner will find it advantageous to supplement his studies by the use of other works that give more drill in calculation if he desires to become proficient in the subject. The format, press work, and binding are excellent. (F. Z. H.)

RESEARCH AND STATISTICAL METHODOLOGY

By Oscar Krisian Buros. Rutgers, N. J.: Rutgers Univ. Press. VI+100 pages. 1938. $1.25.

THIS work is claimed to be an effort to make available sources and excerpts from critical reviews of all books in the English language in which research or statistics constitute the main theme and which appeared during the interval 1933 to 1938. Most of the references are to works on statistical methods and to manuals for preparing reports and writings on scientific subjects. It is true that a number of books dealing with methods used in some branches of natural science are considered, but works of other branches seem to have been neglected. Chemistry is an example.

A shortcoming, that appears to be important to the reviewer, is the fact that no very complete guide to the contents of the books reviewed is furnished. In many instances a list of the chapter headings were given in the original reviews, but these have been omitted in the excerpts. The reviewer realizes that to have included these tables of contents would have increased the amount of printed matter considerably, but it would have been possible to have coded the subject matter so as to have given the reader a better idea of the contents of each book without unduly increasing the amount of printed matter in the present volume. The Classified Index is helpful but lacks the completeness necessary for the reader to make a selection of all the books in which some special subject is discussed, as for example, tetrachoric correlation or parabolic regression. It is hoped that in future works of this nature some economical, specific, and practical method will be adopted to carry out this idea.

There is much to commend in the work, however, since the excerpts from reviews give the reader the opinions of others regarding any particular work and, although incomplete, some idea of the subject matter is afforded. (F. Z. H.)

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THE AGRONOMIST, HIS PROFESSION, AND AN EXAMPLE OF COORDINATED RESEARCH[1]

RALPH J. GARBER[2]

THE agronomist is truly at the crossroads of agriculture. There passes within view of his vantage point almost the entire panorama of agricultural production. Well nigh every item of human food and clothing has, somewhere along the line from its source to its final synthesis, challenged the interest of an agronomist. Our good friends the horticulturists would likely not admit that the domains of soil tilth, soil organic matter, soil moisture, and soil productivity are exclusively those of agronomy, but I think they would admit readily enough that in the solution of problems involving these factors as they relate to the growth of fruits and vegetables, the agronomist's aid has frequently been sought and received.

The agronomist not only occupies a position that is fundamentally important in agriculture, but in industry as well. Much industrial production is dependent upon successful crop production. Problems of land use adjustment and soil conservation which affect both urban and rural peoples require the guiding hand of an agronomist to help in their solution. One might go on and cite innumerable instances where the interest of an agronomist impinges upon and affects those of his fellow man, but this is unnecessary.

THE AGRONOMIST

With such a range of interest, what sort of an individual is an agronomist? Zoologists tell us he belongs to *Homo sapiens* (but let me hasten to add that the first part of the specific name, "s-a-p", has no sinister connotations). This classification, in common with other men, places agronomists in the same general family with monkeys. Please note that I am not even remotely referring to the possible relationship between men and monkeys, but simply pointing out to you the particular pigeon hole into which experts on the classification of animals have thrust the agronomist. I am very eager to make this

[1]Presidential address presented before the thirty-second annual meeting of the Society, New Orleans, La., November 23, 1939.

[2]Director, U. S. Regional Pasture Research Laboratory, Bureau of Plant Industry, State College, Pa.

point clear, if for no other reason, than that I do not wish to start an argument that might well engage our wits and prejudices for days without end.

The cytologist tells us that each cell of an agronomist contains 24 pairs of chromosomes that comport and disport themselves as only such bodies can. He assures us that one member of each pair is paternal and the other maternal in origin. He also advises that one of the 24 pairs has a peculiar significance for us. I refer to the sex chromosomes. If our paternal ancestor had given us an x-chromosome, instead of a y-chromosome, we would have been more likely to become an agronomist's helpmate than an agronomist. Be that as it may, these 24 pairs of chromosomes have played a very important role in determining the final product, man, for they are the bearers of genes, the fundamental units of heredity, if not of life itself.

In our primordial existence and later throughout life these chromosome pairs behave with a nicety that is truly astounding. Just previous to the formation of eggs or sperm, corresponding members of chromosome pairs may exchange comparable segments, then disjoin so that each egg or sperm that is eventually formed is allotted 24 chromosomes—one member of each pair contained in the body cells. When the egg is fertilized with a sperm the normal number of chromosomes, 48, is restored. From this original fertilized egg throughout life, each cell division characteristic of growth is preceded with a splitting of each chromosome to form two new chromosomes; thus, the mechanism is provided that assures each descendent cell its normal complement of chromosomes.

As may be inferred from what has already been said the chromosomes in themselves would not be of such great importance if it were not for the fact that they carry the hereditary factors. This is the opportune moment to call in the geneticist, or "gene chaser", as he is sometimes inelegantly, but quite descriptively, called. He tells us that each chromosome contains scores, if not hundreds, of genes. If this is true—and the veracity of the geneticist is seldom questioned—it may be of interest to pause and reflect a moment on the possible diversification of natural endowments among incipient agronomists. If we assume that each chromosome carries but a single gene, there would be possible a total of 282,429,536,481 different combinations as a result of disjoining and rejoining independently 24 pairs of chromosomes. From this it is easy to see that even if we assume but a few genes in each chromosome there is little likelihood of finding two agronomists alike in anything except perhaps in subject matter interest.

Where does this dilution of sense with a bit of nonsense lead us? I hope it will serve to show that the scope and functions of the agronomists are broad and varied, but fortunately agronomists collectively represent an array of talents fully capable, when harmoniously symbiotic, of handling successfully the many agronomic responsibilities.

THE AGRONOMIST'S PROFESSION

Agronomy comprises several of the so-called pure sciences anastomosed. It is concerned with growing bigger and better crops more

efficiently, without at the same time losing the soil, that most valuable aid in man's struggle for the elusive "abundant life". Early in our history it was not uncommon for a single agronomist to have under way experiments dealing with crop rotation, tillage, variety testing, fertilizers, and plant selection, to say nothing of his teaching and extension duties. In those days the agronomist was truly a man of broad intersts. I am somewhat fearful at times, in our present era of intensive specialization, lest we lose perspective and balance in our agronomic investigations. Perhaps we should maintain general experimental farms to determine how well new procedures and improved varieties fit together to make a successful farm enterprise. In this connection I would like to commend for your later attention the Presidential address of R. G. Stapledon, Director of the Welsh Plant Breeding Station and Imperial Bureau of Pastures and Forage Crops, delivered before Section M (Agriculture) of the British Association for the Advancement of Science and published in Volume 6, Number 3, of the Herbage Reviews for 1938. I shall content myself at this time with a brief quotation from page 141:

"The major aim of agronomical research, which is essentially field research, is to study all the factors which are operative at once and together, and in their natural interplay, for 'nature is a theatre for the inter-relations of activities'. Such a procedure, it may be said, is impossible or at least unscientific. It is certainly not impossible, and if it is unscientific it will yet remain agronomical, and many of the problems of agriculture are more likely to be solved, shall I say, by agronomical investigations than by scientific research, while nearly all the results of scientific research have to pass through the sieve of an immense amount of agronomical investigations before they can be other than positively dangerous to the practitioner."

While we may sometimes dream in retrospect and express a yearning for some of the good things of the past, we are all fully aware that agronomic progress has come about through agronomic specialization. We are no longer content with trial and error methods, we are interested to know why a thing happened as well as to know it did happen.

Agronomy for the most part has changed from a profession of generalists to one of specialists and incidental to this transformation has become more analytical and perhaps less synthetical. The tendency now is for the research agronomist to analyse his problems in terms of soil chemistry, soil physics, soil microbiology, cytogenetics, or physiology, and evaluate and interpret experimental data relative to the solutions of these problems in definite quantitative terms. Methods both in the laboratory and in the field have been greatly improved.

As an example of progress in methods one may cite the evolution of field experiments. It is a long step from the one plot per treatment of a few decades ago to the present two dimensional pseudo factorial arrangement. The results obtained from the earlier experiments were interpreted largely by the use of the personal equation; now we analyze variance with the aid of a calculating machine to arrive at an entirely impersonal result. Perhaps we have gone too far in this di-

rection. Certain agronomists have been so unkind as to suggest that a sort of statistical phobia has supplanted common sense. Be that as it may, I think even the most rabid anti-anything-statistical would admit that mathematical analysis has had a profound influence in the refinement of field experiments.

At one of the recent annual meetings of our Society an eminent plant physiologist expressed surprise at the high level of plant physiological understanding among agronomists. In a different session of the same meeting a well-known geneticist, in opening a symposium before a group of plant breeders, explained at great length some of the modern genetic viewpoints and inferred that the group was unfamiliar with them. He soon discovered to his chagrin that the explanations were unnecessary and the inference incorrect.

The soil agronomists have gone even further than the plant agronomists in specialization as evidenced by the following self-imposed classifications: soil physics, soil microbiology, soil genesis, morphology and cartography, soil chemistry, soil fertility, and soil technology. I presume soil conservation might be added; or is the activity under this category as yet too broad to be called specialized?

With all these ramified and somewhat diverse interests within the agronomic fold, I submit that no one agronomist is learned enough to be a master in each field or broad enough to see all angles of an agronomic problem. I suspect that extension agronomists more than any other group feel the need of tieing together and interpreting for practical farm conditions the many technical results being made available to them by the research agronomists. What are we going to do about this situation? I am not conceited enough to think I have the final answer, but with your permission I would like to describe briefly a cooperative attempt to coordinate and integrate pasture research in the northeastern states as an example of one way to facilitate the convergence of divergent approaches toward a single objective.

AN EXAMPLE OF COORDINATED RESEARCH

The directors of the twelve agricultural experiment stations in the northeastern United States have been holding annual meetings for many years to discuss problems of mutual interest. When the funds under Title I of the Bankhead-Jones Act of 1935 became available this group recommended that a laboratory for pasture research be established somewhere in the Region. After a survey of the available sites it was decided to locate such a laboratory at State College, Pennsylvania. The functions of the laboratory, which is financed by Bankhead-Jones funds assigned to the Bureau of Plant Industry of the U. S. Dept. of Agriculture, are to serve as the focal point for coordinating and integrating pasture research in the northeastern states and to carry on fundamental research not already adequately provided for in the Region. I have used the words "to serve as the focal point" advisedly and purposefully, since this is a democratic, not a totalitarian venture.

SOME AGRICULTURAL CHARACTERSITICS OF THE NORTHEAST

Before detailing some of the more significant steps in this enterprise it may be well to describe very briefly some of the pertinent agricultural characteristics of the Region. The soils for the most part are of glacial origin, although residual soils derived largely from limestone, shales, or sandstones are found in certain areas, particularly in Delaware, Maryland, New Jersey, Pennsylvania, and West Virginia. The soils vary from light sands to heavy clays and from unproductive to highly productive ones. The topography varies from narrow plains and valleys to hills and mountains. Much of the area is woodland, or cut-over woodland that should be replanted to trees. Other large areas are suited primarily to a grassland type of agriculture. The precipitation is usually adequate for luxuriant growth, although during July and August the weather may be dry and hot. The northeastern United States embraces one of the most important milk-marketing regions in the world, both from the standpoint of production and consumption.

Pasture, when available, is the most economical source of feed for the dairy cow so perhaps the most important pasture problem is to provide adequate herbage for grazing throughout the entire growing season. Increased production at a lower unit cost, improved quality, and greater palatability are other important considerations. The solution of these problems is complex and demands a diversified approach. Moreover, pasture research men in the northeastern United States, while in essential agreement as to the objectives to be attained, differ widely in opinion as to the most effective methods of attaining those objectives. From a research point of view this is a stimulating situation but at the same time one that requires a cooperative approach if the research is to be coordinated. This is perhaps the strongest reason why the directors of the twelve northeastern states urged the establishment of a regional pasture research laboratory.

A PLAN FOR COORDINATION

A memorandum of agreement was drawn up, setting forth in broad terms the objectives of the Laboratory and the respective responsibilities of the Bureau of Plant Industry of the U. S. Dept. of Agriculture and the twelve agricultural experiment stations concerned, i.e., Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

To effect a close coordination in the pasture research of the Region, a collaborator was appointed to represent each state station cooperating with the Laboratory. The collaborators meet annually with the Laboratory staff and other representatives of the U. S. Dept. of Agriculture to help plan, coordinate, and integrate fundamental pasture research in the northeastern United States regardless of whether the work is supported by state funds, federal funds, or both.

As a guide in furthering this undertaking a statement of policy was drawn up and mutually accepted by the agencies concerned. I shall not attempt to repeat the full statement at this time, but some of the more significant features may be of interest.

It was agreed that all phases of the current pasture research projects, which are likely to yield information of regional interest, would be reviewed with a view to determining their suitability or to modifying them to fit into a coordinated plan. It was not the intention, of course, to assume direction over the work of any station. The idea was merely to analyze frankly and to plan a coordinated program on the fundamental aspects insofar as such action is practicable from an administrative standpoint. Any recommendation made by the collaborators which involves the discontinuance or initiation of a major line of pasture research in a given state will first be reviewed and passed upon by the director of that state station and by the administration of the Pasture Laboratory before it is made a part of the regional research program.

It was agreed that the Laboratory's researches should pertain particularly to lines not already adequately provided for and directed along lines most likely to yield information of regional interest. Similarly research conducted in cooperation with a state station should be of the type likely to yield basic information. If the Laboratory develops new strains or strain combinations of pasture plants or discovers new facts which appear to possess merit from the farmers' standpoint, they should be thoroughly tested in cooperation with state workers, who, in this case, preferably would assume the major responsibility for carrying on the work.

During the somewhat more than two years of the Laboratory's existence the collaborators have held three meetings and have sponsored two meetings of plant breeders interested in pasture improvement in the Northeastern Region. Frequent exchanges of professional visits among individuals engaged in pasture research in the Region have been promoted, in addition to the occasional group meetings. Any instrumentality which will serve to bring research men working in similar fields together to become better acquainted, both professionally and personally, is useful, since one of the greatest obstacles to overcome in promoting cooperation and coordination is mutual misunderstanding.

The collaborators have facilitated a free exchange of project outlines dealing with pasture research between the State stations and the Laboratory. All project outlines of the Laboratory are kept up to date and filed with each cooperating State station. Likewise, the project outlines of the State stations are on file at the Laboratory. The annual report of the Laboratory, a copy of which is sent to each cooperating agency, includes also a progress report of the pasture research under way at each State station. The collaborator is responsible for assembling this material at his particular station.

As a more or less direct outgrowth of these activities cooperative projects have been drawn up under which certain state stations and the Laboratory are cooperating in a breeding program. In these projects the Laboratory is giving most of its attention to the fundamental aspects underlying methods of breeding, whereas the state stations, in addition to some of the fundamental aspects, are giving particular attention to breeding with the definite objective of producing improved strains for the particular conditions under which they are to

be grown. This kind of cooperative arrangement seems necessary to make effective progress. With a Region as diversified in soil and climate—to say nothing of variation in pasture management practices—it is hardly reasonable to expect that a centrally located laboratory, even though it were physically possible to do so, could breed improved forms for the whole Region. Moreover, in such a comparatively new field there is need for pioneering in ways and means of bringing about improvement by breeding and it seems logical that the Laboratory should devote a considerable share of its attention to this phase of the work.

In addition to this more or less formalized approach to research on a regional basis, informal methods are likewise encouraged. An example may be cited. Two project leaders in the Region, one at a state station and one at the Laboratory, discovered through an exchange of letters, that they were contemplating similar composition studies of pasture grasses. By mutual agreement it was decided that one of them should study one species and the other another species. By correspondence and occasional personal conferences, these two men are keeping in close touch with the progress of one another's work. Such an arrangement, it seems to me, is one of the most effective means of coordinating research.

I have used the terms cooperation and coordination with a slight difference in meaning, a difference primarily of degree. It is generally true that we cannot have coordination without cooperation; it is particularly true in attacking a problem so involved and with so many possible angles of attack as has pasture improvement in the northeastern states. On some phases of this problem it may be mutually advantageous for two or more stations, state or federal, to carry on a specific research project in close cooperation with one another. On the other hand, in some cases it may be more expedient for individual stations to assume major responsibility for developing certain phases of the problem and thus, by concurrence, bringing about effective coordination.

I like to think of our regional approach to pasture improvement in the northeast as an arrangement whereby all research facilities, including both personnel and available equipment, regardless of the funds supporting them, are brought together, scrutinized, appraised, and, by mutual agreement, guided and made use of along the respective lines which seem most effective toward achieving the common objective—acquisition of the facts underlying pasture improvement in the Region concerned.

RESEARCH AT THE LABORATORY

What I have said about the approach to pasture research on a Regional basis applies equally well to the research of the Laboratory itself, but on a smaller scale. We have brought together at the Laboratory a number of research specialists with different viewpoints and training, but all with a common objective—contributing something of regional interest in pasture research. At present the group includes a physiologist, a soil chemist, two cytogeneticists and plant breeders,

a biochemist, and a plant pathologist. These six project leaders are working on the same pasture species, but from different angles.

The research of the laboratory is organized around two main-line projects, (1) cytogenetics and breeding and (2) physiology. As source material thousands of individual plants of the important pasture species are being grown in the nursery. This material came from both seeds and plants collected in pastures of the Northeast, as well as from seed from important producing areas in the United States, Canada, and other countries.

The breeding and cytogenetic investigations have for their immediate objectives the discovery of fundamental facts helpful in planning an intelligent breeding program and the isolation and cataloging, with respect to specific characteristics, of more or less true-breeding strains. At present the cytogeneticists are concerned with such questions as self- and cross-compatibility, effect of inbreeding, chromosomal relationship to plant characters and behavior, species crosses, the efficacy of colchicine in producing chromosomal reduplication, and methods of evaluating, for pasture purposes, individual plant types.

In the physiological studies emphasis is being placed on temperature and water relations to plant growth, the relation of intensity and duration of light to fruiting and vegetative growth, and plant food reserves in the underground parts in relation to top removal and fertilizer treatment. The responses of different clones of the same species to different nutrient levels both in soil cultures and artificial gravel media is receiving considerable attention. In the composition studies the variation among individual plants of Kentucky bluegrass with respect to crude protein and among individual plants of white clover with respect to certain minerals are being determined. The cyanogenetic glucosides of white clover and the carbohydrate fractions of some of the grasses are other subjects under investigation.

The pathologist is working in an almost virgin field in the pasture plants. Of necessity, he at first is concerned with a survey to determine what are the most destructive diseases in pastures. He must work out life histories of the pathogen so as to enable him more intelligently to plan control studies. In the pasture species practical control of diseases is most likely to come from breeding for resistance, hence the pathologist must work out methods of inducing artificial epiphytotics so that he and the plant breeder, working together, may make effective progress in breeding for resistance.

One of the fundamental problems in which the Laboratory is interested is variation, either natural or induced, within pasture species. Perhaps I can illustrate an approach to this problem in one species by citing an actual example. The plant breeder is studying 81 different plants of Kentucky bluegrass asexually increased in sod plots as a first step in determining their potential pasture value, the cytogeneticist is investigating their method of reproduction, the soil chemist is studying the response of some of these same clones to different levels of phosphorus and nitrogen fertilization in soil cultures in the greenhouse, the physiologists are studying the relative effectiveness of water utilization of some of the clones and making a survey of the

variation in their crude protein content, and, finally, the plant pathologist is determining their relative resistance to Helminthosporium "leafspot". If time permitted, I could cite other examples of similar nature, but I think this one suffices to illustrate coordinated and cooperative research among members of the Laboratory staff.

In closing I offer my apologies for protracting this example of coordinated research to such a length and for the rather frequent digressions. If there is a grain in the chaff which I have winnowed before you it is the challenge to accept the ever-widening agronomic responsibility by effective cooperation.

THE HAZARD OF BASING PERMANENT GRAZING CAPACITY ON *BROMUS TECTORUM*[1]

GEORGE STEWART AND A. E. YOUNG[2]

DATA obtained during the 1937 and 1938 grazing seasons in Gem County, Idaho, make clear the extremely great economic hazard and the management difficulties involved when the perennial grazing capacity is based on the fall-annual grass downy chess (*Bromus tectorum*) locally known as cheatgrass. This hazard consists largely of two elements, somewhat related to each other but still more or less distinct. They are (1) the wide variations in forage production from one year to another, and (2) the uncertainty as to whether there will occur any production great enough in volume to serve as a basis for livestock grazing. These statements deal with both relative and absolute values and derive most of their importance from the comparison between downy chess and the perennial plant species that only a few years ago constituted most of the plant cover on this area and yielded most of the forage for livestock.

ECOLOGICAL HISTORY

A brief review of the ecological history of downy chess and of the part it plays in the grazing economy of the Intermountain region will help to clarify the nature of the difficulty that has arisen as a result of native perennial forages having been largely replaced by downy chess on many millions of acres of foothill ranges. About 1900—no records are available to establish the definite date—downy chess appeared in northern Utah and began to increase in places where the plant cover had been disturbed, as along roadsides, fence lines, and in old stands of alfalfa. This grass also spread to uncultivated areas, especially where the cover of native perennials had been thinned or so reduced in vigor that there was less than a full natural stand. Large areas of foothill range and adjacent valley edges that had been grazed without restriction by community livestock were soon occupied.

Ranges formerly furnishing some feed throughout much of the summer now bore after the end of June only the tough, straw-colored stalks and hard-toothed seeds of downy chess, dead dry, and highly inflammable. Frequent fires raced over these foothills, and owing to the slenderness of the pedicels bearing the spikelets, these burned through and the seeds dropped to the ground uninjured by fire. The seeds and root crowns of perennial grasses, however, are sometimes injured because the more abundant growth holds the fire longer. During a fire most woody plants are consumed down nearly to the ground line. After a few years these fires, together with unrestricted grazing, brought about nearly pure stands of downy chess. When no fires occurred the seeds shattered and were dispersed naturally.

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[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah, and the Soil Conservation Service. Received for publication September 18, 1939.

[2]Senior Forest Ecologist and Assistant Range Examiner, respectively.

Autumn rains enable the downy chess seeds to germinate and the seedlings to develop considerable grass clumps before the coming of snow, under which they lie dormant until spring. The first warm days stimulate the growth of leaves and flower stalks which proceeds with great rapidity by vitrue of the root and crown development of the previous autumn. This early growth furnishes spring feed for livestock but lasts only about four or at most six weeks before the soft green growth dries and toughens at the time of seed development. In another 3 or 4 weeks the seasonal cycle is completed and during July and August the matured, dry plants are seared with summer heat, and being annuals they show no further activity until fall rains germinate the seeds and start a new crop of seedlings.

The growth of downy chess is markedly affected by both temperature and available moisture at two critical periods, (a) in the fall when seed germination ordinarily takes place and vegetative stooling begins, and (b) again in the spring when flower stalks are sent up and most of the volume of top growth is produced. Should autumn precipitation be so nearly lacking that germination does not take place or that clumps are not developed in the fall, or should the spring be so dry or so cold as to retard top growth, the amount of total vegetation produced is very small.

In an unusually late, cold spring top growth may be retarded until the normal time to begin seed production has arrived, after which during long warm days the soil soon dries out and vegetative growth ceases. Sometimes when cold spring weather delays growth and even when moisture is abundant, seed production takes place while vegetative growth is still meager. In the absence of critical studies, definite statements cannot be made as to all the reasons for retarded growth in late springs. Observation and preliminary tests, however, lead to the opinion that downy brome is so strongly influenced by the length of the daylight period that when the required day length occurs seed production sets in almost irrespective of the height or spread of the vegetative growth. At any rate, in some years heavy seed production occurs on greatly dwarfed plants, though in most years vigor of top growth and high seed production accompany each other.

DISTRIBUTION AND ECONOMIC IMPORTANCE

Downy chess has spread throughout Utah in the intermediate foothill zone, being abundant neither at the high elevations where mountain plants prevail nor in the dry desert valleys where Russian thistle replaces it as the predominant annual on abandoned cultivated land and in the spaces of a weakened plant cover that were formerly occupied by native desert perennials. Downy chess is particularly abundant in the foothills of the Snake River Valley, and especially so in the 200-mile northwest-southeast stretch in which Boise, Idaho, is about centrally located. More recent is its occupation of Nevada, of eastern Oregon and Washington, and of Montana in parts of which it is thought to be still invading.

In Montana particularly, stockmen and staff members of the Montana Agricultural College have within the past few years ex-

hibited considerable concern about its further spread. Many stockmen of the Intermountain region also fear that once downy chess has occupied a tract of range land that perennial forage cannot be brought back. Opposed to this fear is the fact that, on several areas supporting a vigorous growth of native perennials, downy chess has invaded but has not thickened its stand materially.

Critical research is much needed in order to determine under which ecological conditions perennial forage species may be able to invade established stands of downy chess and the rate at which the perennials may become established in the area. Perhaps the competitive superiority of one plant group over the other may differ under differing environments. For example, in the foothill zone of northern Utah and southeastern Idaho where the annual precipitation is 9 inches or more, perennial forages are apparently increasing in downy chess areas on which for a few years grazing has been relaxed and fires kept out. In other words, the better native perennial forage species seem likely, when given a fair opportunity, to be able under fair precipitation to compete successfully with downy chess.

On the other hand, many good observers are of the opinion that where the precipitation is 6 to 8 inches or less, perennial vegetation is not sufficiently vigorous to enable it to replace downy chess, even when the area is very lightly grazed. Many other workers think that in time perennials would return. Unanswered questions have been raised as to whether perennials can in ordinary circumstances make good headway in stands of downy chess; whether in arid conditions such replacement would not be so slow as to make it inadvisable to sacrifice the spring growth of downy chess in order to give the perennials a chance; and whether, as some think, the downy chess is as valuable for forage as the perennials that can be restored under conditions which are unfavorable to the perennials.

The competition between downy chess and native species has taken a new departure in some parts of the region during the last few years, a form of smut (*Ustilago bromivora*)[8] having attacked downy chess but not the native grasses. For example, in 1935 and 1936 this smut was so abundant on the foothill range to the north of Mountain Home, Idaho, that scarcely any seed was produced in that area, greatly relaxing the competition with perennial forages where these were abundant enough to take advantage of the open spaces in the plant cover.

Downy chess, though a much used grazing plant, is not in the true sense highly palatable. Its value for grazing is limited greatly by the fact that the leaves are both hairy and sparse, and that the period during which it is fresh is short. As the time of seed maturity approaches its stems become tough and wiry and its seeds hard with toothed lemmas, often lodging in the softer tissues of the mouths of livestock, particularly of young animals. In warm moist springs, however, for about a month before seed begins to develop and the stems get tough, the leaves and early stem growth are eaten readily by both cattle and sheep, as is also the new growth that springs up in autumn after good rains. Horses have been shown to be able during

[8]U. S. Forest Service Range Plant Handbook, sheet G38 (1937).

summer nearly to maintain themselves in good condition of flesh and liveliness when they had access to an abundance of pasturage consisting of 89% of dried herbage and seeds of downy chess.[4] The many millions of acres of spring and fall range occupied by it and the extreme scarcity of perennial grasses make it a highly important feed. In fact, it is so much used during the range lambing season that many stockmen regard it as their principal source of spring feed. This tends to obscure the importance to stockmen of restoring the good perennial grasses which are more palatable, produce higher yields of forage, do not have toothed seeds, and keep soft for 8 to 12 weeks in comparison with 4 or 6 weeks for downy chess. The completeness with which downy chess occupies a favorable area greatly retards, though under ordinary precipitation it probably does not prevent, the increase of perennials. The abundance of downy chess, however, increases the fire hazard, and thereby tends indirectly to keep out perennials altogether.

RANGE SURVEY OF GEM COUNTY, IDAHO

During the summer and fall of 1937 an interagency range survey, known officially as the Western Range Survey, was conducted in the western United States. As part of this survey, Gem County in Idaho was completely covered and several other Idaho counties partly covered. For Gem County a vegetation type map was prepared and the forage inventoried at the minimum survey intensity of 10 plots to the section by the point-observation-plot method.[5] From this survey, grazing capacity in cow-months was calculated and tabulated on a map within vegetation types by sections. As a whole, the reported grazing capacities were much lower than was thought to be correct by the stockmen who were using these lands, and who were to be allowed A.A.A. benefit payments in proportion to the grazing capacity of their range lands.

When the time for the next grazing season was at hand, it was clear that the grazing capacity for 1938 was much higher than that reported for 1937. This led to a re-examination of the area by the Intermountain Forest and Range Experiment Station. The procedure consisted of visiting about 20 typical areas in the county and examining such areas closely, after which forage conditions on a larger surrounding area were noted in a more general fashion. By far the greater part of the vegetation on most of the re-examined areas was found to consist of downy chess, with which was interspersed a few annual weeds, and in some parts of the area, a very sparse but well-distributed cover of bunch bluegrass (*Poa* spp.). The forage production in 1938 was therefore tabulated as a distinct reading and compared with the WRS map showing the grazing capacity of 1937 as another distinct reading. Since a new range survey was not possible, and since, as

[4]Hurtt, L. C. Downy brome (cheatgrass) range for horses. Applied Forestry Notes (mimeographed), Northern Rocky Mountain Forest and Range Experiment Station, January, 1939.

[5]Stewart, George, and Hutchings, S. S. The point-observation-plot (square-foot density) method of vegetation survey. Jour. Amer. Soc. Agron., 28:714–722. 1936.

compared with an entirely new forage inventory, it was much quicker to arrive at an approximation of the 1938 grazing capacity by comparing it with that of 1937 as shown on the WRS map, the 1938 forage production is expressed by a percentage figure that indicates the amount by which it exceeds that of 1937.

PRECIPITATION AND FORAGE GROWTH

The more abundant protection of downy chess in 1938, as compared with that of 1937, is accounted for by several climatic conditions. The precipitation in 1938 was about double that of 1937 and the 1938 crop was further helped by approximately 5 inches of precipitation during the three fall months of September, October, and November 1937, when downy chess was beginning growth, as compared to practically none during the same months of 1936. These data and also the fact that the spring rainfall of March, April, and May when this grass grows most rapidly was about 75 to 80% greater in 1938 than in 1937, are shown in Table 1 and Fig. 1. During the cold, snow-covered winter of 1936–37 little germination and practically no growth took place until March; whereas, during the mild, rainy winter of 1937–38 full germination occurred in September and growth continued almost without cessation from that time till the seed matured in June.

This timely and abundant precipitation and the open winter so favored the growth of downy chess that the grazing capacity in 1938 was much higher than that obtained for 1937, owing largely to the increased production of downy chess, but in a minor way to some forage production by native bunch bluegrasses not reported in the 1937 survey. These grasses were missed at that time because of their dry scorched condition in the late summer when they are normally dormant. The local Soil Conservation Service workers had already found the bluegrasses and had arrived at the same conclusions with reference to increased grazing capacity, having taken a considerable number of check estimates on typical areas of the county.

A careful examination of the forage on the ground, of the data which the Soil Conservation Service had taken, and of the additional information gathered at the time of the check survey, all show the tremendous variation in the forage produced from one year to another and from one small area of land to another by the annual downy chess. This plant is the only annual plant in Gem County requiring much consideration in this study, but it is thought that the same wide variation would occur in almost any area in which either this plant or another annual constituted most of the plant cover, and had been subjected to as great a variation in the total quantity of precipitation and in the distribution of that precipitation as occurred in Gem County when 1938 is compared with 1937. Perennials also vary widely in forage production from year to year but as will be seen they were much more dependable than annuals in Gem County.

DATA OBTAINED BY RE-EXAMINATION

Three general soil conditions prevail in Gem County, namely, (1) loose granitic sands, (2) fine-grained basaltic soils, and (3) ancient

Payette lake-bottom soils. The behavior of the downy chess on these respective soil types was in the main rather distinct. On the granitic soils a luxuriant growth of downy chess was produced in 1938, from 100 to 200% greater than that of 1937, whereas on the basaltic soils the increased growth, though marked, is much less than on the

TABLE 1.—*Precipitation by months for the two downy chess growing seasons of 1937 and 1938 at Sweet, elevation 2,450 feet, and Brownlee, elevation 4,000 feet, Gem County, Idaho.*

Sweet			Brownlee		
Month and year	Inches		Month and year	Inches	
August 1936	0.24		August 1936	0.27	
September	—		September	—	
October	—	0	October	0.15	0.16
November	—		November	0.01	
December	1.27		December	0.97	
January 1937	2.82		January 1937	3.57	
February	1.38		February	2.48	
March	1.80		March	2.44	
April	1.72		April	2.81	
May	0.90		May	0.80	
June	0.69		June	1.48	
July	—		July	0.07	
Total	10.92		Total	14.95	
August 1937	—		August 1937	0.01	
September	—		September	0.24	
October	1.62	5.16	October	1.43	4.92
November	3.54		November	3.25	
December	3.25		December	4.32	
January 1938	4.07		January 1938	2.83	
February	1.68		February	2.99	
March	3.67		March	5.47	
April	2.80		April	1.27	
May	1.36		May	3.40	
June	0.93		June	1.66	
July	0.90		July	0.82	
Total	23.82		Total	27.69	
	1936–37	1937–38		1936–37	1937–38
Total, Sept., Oct., Nov.	0	5.16	Total, Sept., Oct., Nov	0.16	4.92
Total, Mar., Apr., May	4.42	7.83	Total, Mar., Apr., May	5.95	10.14

granitic soil, being 40 to 85% greater than that of 1937. On the Payette lake-bottom soils the total growth and the increased production over that of 1937 were greatest of all, the forage production being approximately three to ten times as great in 1938 as in 1937 and averaging five times as great. The weak response of downy chess in 1937 and of the small bunch bluegrasses that were missed altogether because of having dried completely, probably caused the reported 1937 grazing capacity to be somewhat lower than it actually was,

but not markedly so because the plants missed are low producers and thinly scattered.

Since forage production was widely variable in different parts of the area, the range lands in that part of the county below the forest boundaries was divided into 10 districts and the forage conditions for

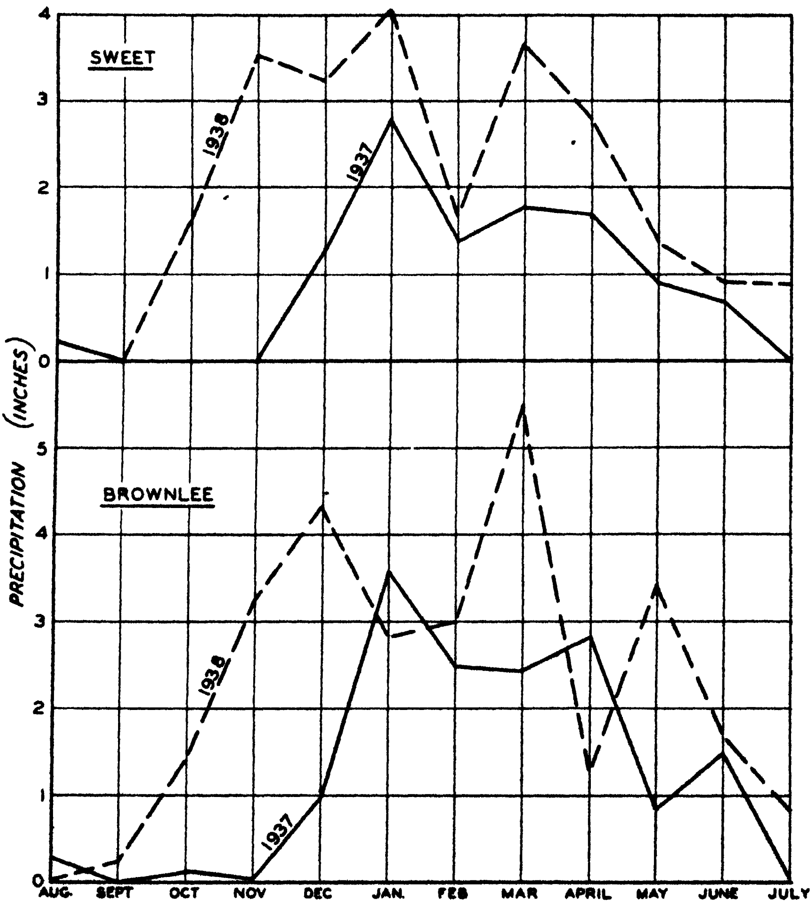

FIG. 1.—Precipitation for two growing seasons of downy chess (*Bromus tectorum*), 1937 and 1938. Since this plant is a fall annual the precipitation of late summer and autumn affects its growth markedly. March and April are the critical months of spring.

each reported separately. The figures are given as percentage additions to the 1937 forage production that are necessary to obtain the forage production for 1938 for respective districts. For example, in district No. 1 a given section of land, i.e., a square mile, having forage for 60 animal-months in 1937 had a capacity greater by 60% of 60, or 36 animal-months, establishing a figure of 96 animal-months for 1938.

The acreages and the percentages by which the 1938 grazing capacity was greater than that of 1937 as shown on the WRS map are summarized by districts in Table 2.

TABLE 2.—*Percentages by which the 1938 forage production exceeded that of 1937 in the 10 districts of Gem County, Idaho, lying below the national forest boundaries and having the kind of soil specified.*

District (nonforest)	Location*	Thousands of acres	Excess of 1938 over 1937, %	Kind of soil†
1	T. 11*, 12*, N.	35	60	Ba
2A	T. 10 N. east of Squaw Creek	10	150	Gr
2B	T. 10 N. west of Squaw Creek	11	85	Ba
3	T. 9 N.	48	200	Gr
4	T. 8 N., E 1/2; also R. 1 E. and 2 E*	16	50	Ba
5	T. 8 N. W 1/2 R. 1 E. also E 1/3 R. 1 W.	19	40	Ba
6	T. 8 N. W 2/3 R. 1 W., also R. 2 W*.	22	400	Pay
7	T. 7 N. W 1/2 R. 1 W.; also 2 W.* and 3 W*	28	400	Pay
8	T. 7 N. E 1/2 R. 1 W.; also R. 1 E.* and 2 E*	27	100	Gr
9	T. 6 N. W 1/3 R. 1 W.; also R. 2 W.* and 3 W*	22	85	Ba
10	T. 6 N., E 2/3 R. 1 W., also R. 1 E*	35	150	Gr
Total		273	Av. 167+	

Summary by Soil Type

Soil type	District No.	Percentage increase to 1937 to get 1938	Average percentage increase
Basaltic	1, 2B, 4, 5, 9	60, 85, 50, 40, 85	64
Granitic	2A, 3, 8, 10	150, 200, 100	150
Payette	6, 7	400, 400	400

*Signifies only parts of townships included in 1937 map.
†Ba = basaltic soils; Gr = granitic soils; Pay = Payette soils.

An examination of the divergent yields in the 10 districts into which the county was arbitrarily divided shows that it is not possible to give a blanket figure for the entire area of the county, though Table 2 shows a purely calculated weighted average which from the table is seen to apply to not a single one of the 10 districts. The relative amount of vegetation in 1938 as compared with that of 1937 also differed widely and irregularly on various soils, the 1938 forage production being on the average greater than that of 1937 by 64, 150, and 400% for the basaltic, granitic, and Payette soils, respectively. This comparative difference resulted largely from differences in the nature of the soils themselves and in the depth of soil available for root occupation, Payette soils being as a whole several feet deep. Since extremely shallow soils with a depth of only 2 to 4 inches above bedrock, as on many basaltic soils, produce less forage than those

that are 20 to 60 inches in depth, the great variations in production on different areas in the same soil type are easy to explain.

THREE TYPE AREAS

In Table 3 and Fig. 2 are given the data for 1937 and 1938 on three areas, each rather typical, respectively, (1) for nearly pure stands of downy chess, (2) for downy chess intermixed with perennials, and (3) for a stand consisting largely of perennials with a little downy chess.

TABLE 3.—*Forage production in Gem County, Idaho, in 1937 and on the same areas in 1938 on sites fairly representative of areas predominated by downy chess, intermixed downy chess and perennials, and largely perennials with some downy chess.*

	1937		1938	
	Density	Forage acres per 100 acres	Density	Forage acres per 100 acres
Mostly downy chess (T. 8 N., R. 1 W., Sec. 31):				
Bromus tectorum	0.35	0.1225	3.15	1.1003
Poa spp	Trace	Trace	0.45	0.09
Festuca arida	—	—	0.40	0.28
Total	0.35	0.1225	4.00	1.3803
Mixed downy chess and perennials (T. 7 N., R. 2 W., Sec. 3):				
Bromus tectorum	1.75	0.610	3.50	1.225
Poa spp	0.50	0.350	0.30	0.100
Festuca arida	—	—	0.50	0.210
Erodium cicutarium	—	—	0.15	0.030
Total	2.25	0.960	4.45	1.565
Largely perennials; some downy chess (T. 11 N., R. 1 E., Secs. 11 and 12):				
Bromus tectorum	0.44	0.154	0.65	0.2275
Perennial grasses	0.89	0.573	2.55	1.6150
Perennial weeds	5.15	0.807	1.55	0.862
Total	6.48	1.534	4.75	2.7045

PERENNIALS VS. ANNUALS FOR FORAGE

The perennial vegetation, a remnant of the original cover which consisted largely of perennial species, is shown in Table 3 to be much more productive as a source of feed, yielding in total volume (2.7045 forage acres per 100 acres) during the favorable year (1938) nearly double as much forage (1.3803) as did downy chess, and in the unfavorable year (1.534 forage acres compared with 0.1225) more than 12 times as much. Perennial vegetation is also much more dependable, producing in the definitely unfavorable year of 1937 approximately the same amount of forage (1.534) as did the mixed perennial-

downy chess area (1.565) in the unusually favorable year of 1938 and 11% more than did the nearly pure stand of downy chess (1.3803). Such wide fluctuations in forage yield when added to the short duration of its availability create in the case of stands of downy chess

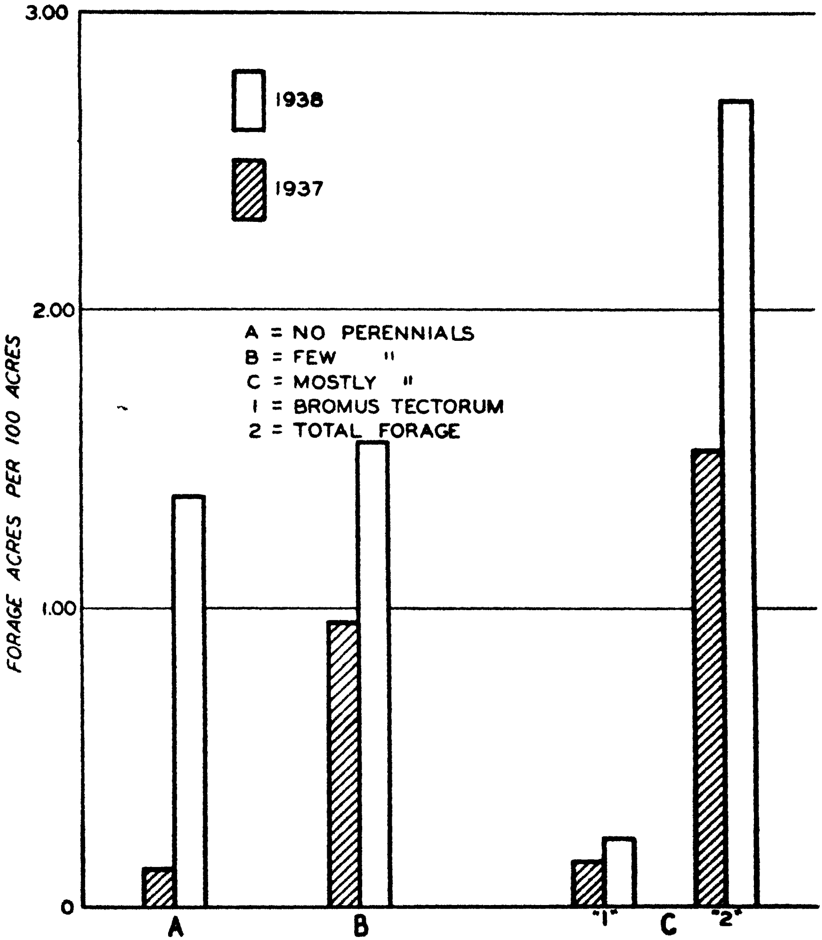

FIG. 2.—Forage produced in Gem County, Idaho, during 1937 and 1938 on the same areas, typical for (A) nearly pure stands of downy chess (*Bromus tectorum*); (B) mixed stands of downy chess and native perennial forages; and (C) nearly pure stands of native perennials. Comparatively the native perennials are much more reliable forage producers in years of unfavorable precipitation.

greater difficulties than stockmen can be expected repeatedly to overcome. On the other hand, the area that bore mostly perennials produced 57% as much in the unfavorable year (1.534) as in the favorable one (2.7045), a reduction in forage which, though drastic, is

much nearer to the adjustment that stockmen might be able to make and still preserve economic stability.

The extreme variation in forage production from year to year and from one spot to another in the county points out specifically that where the vegetation consists largely of annual plants it is extremely difficult to make a grazing plan that is applicable beyond the current year. On the other hand, where the vegetation consists largely of perennial plants and of a sort good for forage, the data here presented show that the yields to be expected in unfavorable years are much higher and the variations from spot to spot and from year to year are very greatly reduced on a percentage basis. The difference in forage production by perennials between a season with a low precipitation and another season with a precipitation more favorable is great but does not even approximate the relative magnitude of differences shown during the same years and on similar sites by annual plants. Moreover, these grass annuals require moisture during a short period of a few weeks in the fall when they begin growth and again in the spring when they must grow rapidly if they are to make a good volume of forage during the season. Precipitation which comes after this period has passed is almost entirely lacking in effectiveness for annuals, whereas with perennials, many of which can grow whenever moisture is available, late moisture, though less effective than early, is still of considerable value. In 1937 moisture was very scarce or almost lacking during the period when downy chess makes its vegetative growth. Because of this, the survey of 1937 shows an extremely low production, and that of 1938 when the moisture was favorable both in amount and distribution, shows the large increases already described.

DATA FROM BOISE NATIONAL FOREST

Data that are highly corroborative of the conclusions in Gem County are presented in Table 4 and Fig. 3 in which are given the number of plants and the density of cover for a tract of similar range on the Arrowrock addition of the Boise National Forest in Idaho, about 60 miles southeast of Gem County. Dense stands of downy

TABLE 4.—*Number of plants and density of cover of downy chess in 1930 or 1931 and in 1936 or 1937 as indicated, Arrowrock addition of Boise National Forest.*

Area	1930 or 1931		1936 or 1937		Density 1931 × 1936 or 1937
	No. of plants	Density	No. of plants	Density	
Cow Creek*...	1,324	0.067	635	0.003	22.3×
Arrowrock					More than
Plot No. 1†	2,350	0.102	6	Trace	200×
Plot No. 10‡	1,108	0.098	2	Trace	200×

*Data for 1931 and 1937.
†Data for 1930 and 1936.
‡Data for 1931 and 1936.

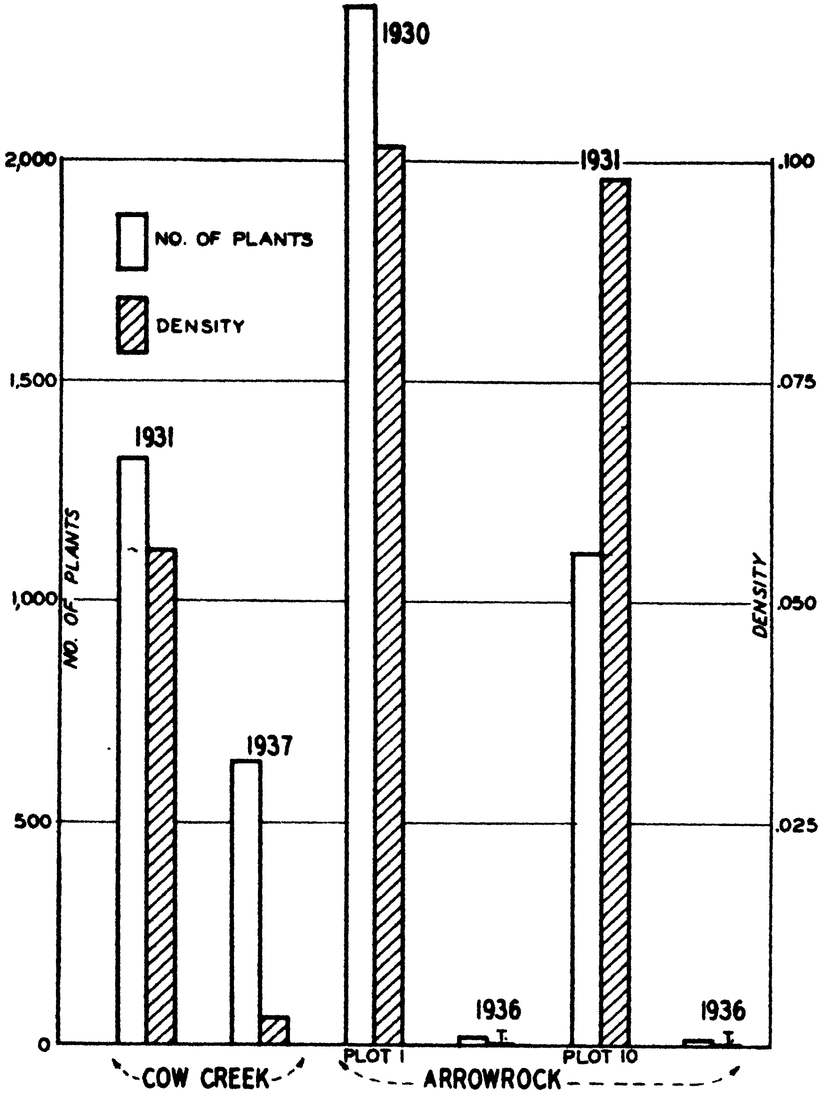

FIG. 3.—Number of plants and the forage produced (density) of downy chess (*Bromus tectorum*) in 1930 and 1931 when growing conditions were favorable and in 1936 and 1937 when precipitation was low and when a smut epidemic attacked downy chess but not the native perennial forages.

chess which occurred in 1930 and 1931 were almost nonexistent in 1936 and 1937, owing both to differences in precipitation and to the occurrence of a smut epidemic in the later years. The curtailment in forage production during 1936 and 1937 on this range in Ada and Elmore counties was even more marked than that in Gem County in 1937, the earlier years producing 22 to 200 times more than the later

ones. In 1938 the downy chess was just beginning to recover from the smut epidemic, which constitutes still another means of making forage production uncertain and thereby increasing the difficulty of making the required adjustments in livestock numbers on ranges producing principally downy chess.

Though actual figures for other localities are not available to establish the intensity of fluctuations in forage production from year to year, the variations throughout the Intermountain region are of about the same magnitude as those shown in Gem County. For example, in western Utah, during the extremely unfavorable year of 1934, the forage production of Russian thistle, where this was the predominating species, was only 12% of normal, whereas in 1936 it was nearly 15 times as great, or approximately 180% of normal, so far as normal could be established from the incomplete data available.

SUMMARY

Downy chess (*Bromus tectorum*), beginning about 1900, spread over the Intermountain region, occupying bare and nearly bare areas where the natural plant cover had either been broken or was greatly deteriorated. This plant normally begins growth in autumn when it forms winter tufts from which seed stalks grow rapidly as soon as warm weather comes the following spring. If dry fall weather delays germination till spring, the volume of growth is much smaller. When a dry fall is succeeded by a cold spring, or by a dry one, vegetative growth is extremely dwarfed, as occurred in 1937 in Gem County, Idaho. When moisture is abundant in both fall and spring, growth is vigorous as in 1938.

Downy chess is an important range plant especially on spring ranges because it is widespread and frequently occurs almost to the exclusion of perennial plants. Its high inflammability when dry makes the occurrence of grass fires frequent and these tend to eliminate most of the perennial plants that are still left, but does not injure downy chess. This plant is soft and fresh only during 4 to 6 weeks of spring and much less palatable for cattle and sheep during the remainder of the year, though new fall growth is readily eaten. The old stems are also consumed to some extent in fall and winter when they are soaked by wet snow or prolonged rains. Horses can use at least part of the dry stems and seeds in summer.

In Gem County the 1938 forage production on areas of several thousand acres was from 40 to 400% greater than in 1937. Production also varied widely from one area to another, both on different soil types and within the same soil type, probably owing largely to variations in soil depth and soil moisture.

Forage production on small plats bearing nearly pure stands of downy chess was 5 to 12 times as great in 1938 as on the same plats in 1937. Forage production from mixed stands of perennial plants and downy chess varied much less, and that from nearly straight stands of perennials still less. Remnant stands of perennial forages in moist years yielded approximately twice as much forage as did downy chess, and in years with a dry fall and a dry spring (1937) about 12 times as

much. A smut epidemic on downy chess also reduced its production on the Arrowrock addition to the Boise Forest almost to nothing for the 3 years of 1936–38.

These acute shortages in the yield of downy chess, which may come almost without warning, introduce such a large element of uncertainty into the feed supply program of stockmen that it is extremely hazardous for them to use this plant as a basis on which to establish perennial grazing operations.

SURFACE STERILIZATION OF NODULES WITH CALCIUM HYPOCHLORITE[1]

J. K. Wilson and T. Punyasingha[2]

NODULES on the roots of leguminous plants growing in the soil are exposed to the organisms therein. Decomposing organic matter, as well as that which may come from the nodule into the surrounding soil solution, provides a favorable environment for the development of the native flora. The intimate contact of the nodule with the soil solution in which the organisms develop makes it possible for the comparatively rough surface of the nodule to become impregnated with whatever organisms may be present. From descriptions of the manner in which the root nodule bacteria enter the root hairs and from the histological appearance of the nodule, as well as from its method of development, one might consider that the cells of healthy looking nodules which are below the cortax, and filled with bacteria, may be free from organisms other than the Rhizobium. A few authors have reported, however, that the Rhizobium is seldom a pure growth within the cells of the nodule, and one gets the impression from such reports that certain extraneous organisms are commonly found in the nodules along with the Rhizobium. A summary of such reports and finding is found in the studies of Fred, *et al.*[3] In concluding their remarks, they state that it is highly probable that faulty technic may account for some of the contaminants reported.

Various methods have been employed to remove the undesirable organisms from the surface of the nodules in order to obtain a pure culture of the organism from within the nodule. Some workers apparently prefer a certain method and obtain satisfactory results, while other workers experience difficulty with the method. The method proposed at this time has been followed since 1915.[4] It possesses unusual flexibility and efficiency, and by its use information was obtained concerning the occurrence of extraneous organisms within the nodule.

PROCEDURE

A germicide is probably of most service when it destroys the organisms on the surface of the nodules and does not penetrate in a reasonable period of time to the cells filled with the Rhizobium. It is still better if it soon loses its sterilizing power and leaves no toxic residue when only traces are left on the outer covering of the nodule. A germicide possessing these qualities is found in a solution of calcium hypochlorite.

Preparation of sterilizing solution.—The sterilizing agent is easily prepared, about 10 grams of fresh, dry, ordinary commercial chlorinated lime is triturated with 350 ml of water and filtered. This solution of calcium hypochlorite contains

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication August 31, 1939.

[2]Professor of Agronomy and Graduate Student, respectively.

[3]Fred, E. B., Baldwin, I. L. and McCoy, Elizabeth. Root nodule bacteria and leguminous plants. Univ. Wis. Sci. Studies, 5:1–343. 1932.

[4]Wilson, J. K. Calcium hypochlorite as a seed sterilizer. Amer. Jour. Bot., 2:420–427. 1915.

about 5,000 ppm of active chlorine, a concentration that appears to be satisfactory for this kind of work. It can be stored fairly well in dark bottles under mineral oil.

Nodular material.—Healthy appearing plants are taken from the field and the roots washed in running water to remove most of the adhering particles of soil. The nodules may be removed by forceps, then placed in the solution of calcium hypochlorite where they remain for the desired time. Since the sterilizing agent soon disappears in the presence of organic matter, several hundred times as much solution of calcium hypochlorite as nodular material was used. This prevented a drastic reduction in the strength of the sterilizing agent. Any convenient container will serve as the sterilizing chamber.

Handling nodules and isolations.—After a nodule remains in the germicide for the desired time it is removed to sterile water for 4 or 5 minutes and then into sterile water in a petri dish. It is then crushed to liberate some of the organisms from the cells and handled in the usual manner for making isolations. The nodules can be transferred from the sterilizing solution to the surface of agar in test tubes and either left until the organism appears on the agar or until needed for crushing in the petri dish. By this procedure it is certain that active chlorine has disappeared. Undesirable organisms, if not destroyed, will usually show in the test tube, after a period of incubation. The medium employed contained peptone, salts, and saccharose. Such a medium appeared equally suitable for the rhizobia and for other organisms.

Observations were made of the platings for the rhizobia and for other organisms at intervals of 3 to 6 days, many stained preparations having been examined. In order to make certain that at least some of the colonies which appeared were the rhizobia, parts of many colonies were transferred to slopes and, subsequently, tested for their ability to effect nodulation. The method employed was that described by Wilson.[5]

RESULTS

A method that can be recommended with confidence, to destroy organisms on the surface of nodules when one wishes to obtain the rhizobia that is within the nodule should be applicable to material from many species. The method described above has been followed to destroy the organisms on the surface of nodules from more than 60 species of plants. More than 100 individual nodules have been employed from one species. In Table 1 is given information relative to the time nodules from four species should be immersed in the solution of calcium hypochlorite in order to obtain plates on which nearly all the colonies resemble those of the rhizobia. It is realized that the immersion can be longer for large nodules of certain species than for small nodules of others. This is important because the sterilizing agent should not be permitted to penetrate throughout the nodule. At the same time, the longer the action of the hypochlorite solution continues the greater is the chance of destroying the organisms on the surface or near the surface of the nodule.

Nodules of *Dalea alopecuroides* Willd. were immersed for 20 minutes. In the first plate where the nodule was crushed colonies resem-

[5]WILSON, J. K. Leguminous plants and their associated organisms. Cornell Univ. Agr. Exp. Sta. Mem. 221. 1939.

bling Rhizobium were found in four of the five cases. In the fifth case a mold appeared. In the second dilution only colonies resembling Rhizobium were seen on the five plates. Nodules of Dalea treated for 30 minutes gave similar results. When immersed for 40 minutes they gave many plates on which colonies resembling Rhizobium only were seen. Usually when two dilutions were made too many colonies were present in the plates. Occasionally, however, colonies of bacteria were observed which did not resemble those of the rhizobia. There was no uniformity in such occurrences. Sometimes they were on the plate in which the nodule was crushed, sometimes on the plate of the second dilution, and always appeared as surface colonies. Parts of eight colonies from nodules of Dalea immersed for 20 minutes, parts of four immersed for 30 minutes, and parts of two immersed for 40 minutes were transferred to slopes and without further examination for purity tested for their ability to effect symbiosis. These 14 transfers, each representing a nodule, were apparently pure cultures of rhizobia.

TABLE 1.—*Time of immersion of nodules for sterilization of surface and for obtaining growth of the Rhizobium on plates.*

Nodules from	Immersion time in minutes, probable success		
	Poor	Good	Injury
Dalea alopecuroides	10–15	20–45	60 or longer
Glycine max	15–20	40–120	Longer than 120
Melilotus alba	5–10	15–40	40 or longer
Trifolium repens	5–10	15–60	Longer than 60

Somewhat similar results were obtained when nodules of *Glycine max* (L.) Merr., *Melilotus alba* Desr., and *Trifolium repens* L. were immersed in the calcium hypochlorite solution, washed, crushed, and plated. Also there were 12 transfers, each representing a nodule of *Melilotus alba*. All but one effected symbiosis and this one was from a nodule immersed for 20 minutes. In addition, 22 transfers, each representing a nodule of *T. repens* were made. Of these seven were of nodules immersed for 10 minutes and five each of nodules immersed for 20, 30, and 40 minutes. Only two failed to effect symbiosis. One was from the 10-minute immersion and the other from the 20-minute immersion.

DISCUSSION AND CONCLUSION

A method for treating nodules of leguminous plants to destroy undesirable organisms on their surface has been presented. At the same time this treatment leaves the cells in the center of the nodules full of viable bacteria from which pure cultures of Rhizobium may be obtained. Traces of the hypochlorite solution adhering to the nodule when it is removed from the solution soon disappear and leave no toxic residue. The agent is cheap, efficient, convenient, possesses working latitude, and is easily prepared. When it is used a high percentage

of the colonies on the plates resemble those of Rhizobium. In many instances this is the only type of colony. When colonies develop that were easily identified as not Rhizobium they sometimes were in the petri dish where the nodule was crushed to literate the legume organisms and at other times in the second or third dilution. Their occurrence seemed to bear no relation to dilution or to the fragments of nodular tissue.

From the data presented it appears that the interiors of a vast majority of well-developed, clean, healthy-appearing nodules contain only the legume bacteria and that perhaps most organisms reported as contaminants within the nodule are the result of ineffective sterilization of the surface of the nodule. Organisms other than the Rhizobium that appeared on the platings of nodules after treatment and crushing developed mostly from material insufficiently exposed to the sterilizing agent. Nodules treated for sufficient time to permit considerable bleaching nearly always gave, on plating, colonies resembling those of Rhizobium. Transfers of such colonies when tested on seedlings usually effected symbiosis.

THE EFFECT OF CALCIUM ARSENATE UPON THE PRODUCTIVITY OF SEVERAL IMPORTANT SOILS OF THE COTTON BELT[1]

CLARENCE DORMAN, FREDERICK H. TUCKER, AND RUSSELL COLEMAN[2]

INVESTIGATIONS have indicated that accumulated arsenic in certain soil types has reduced their productivity. Morris and Swingle (6)[3] believed that the incorporation of arsenical compounds in the soil is dangerous practice and may cause considerable injury as the concentration of arsenic increases. Large amounts of arsenic have been found in some virgin soils but greater quantities occur in cultivated soils whose crops have been treated with arsenates for insect control. Many southern soils whose cotton crop is often dusted with calcium arsenate for boll weevil receive considerable quantities of arsenic; therefore, it is of economic importance to determine its effect upon the soil and its possibility of becoming a serious problem to agriculture.

Earlier workers have found that the effect of arsenic depends upon the nature of both soil type and crop. In South Carolina, Cooper, *et al.* (3) have shown that cotton grows normally on some soil types which have received 2,000 pounds of calcium arsenate, but its growth is greatly reduced on other soil types which have received only 50 pounds per acre. They have also reported that different crops vary in response. Rye, corn, sweet potatoes, and tobacco were very tolerant, but cowpeas, vetch, soybeans, cotton, and oats were very sensitive to arsenate applications. In Louisiana, Reed and Sturgis (7) found that cotton treated with calcium arsenate was not affected, but that rice following it was seriously injured.

Investigations have already revealed many interesting facts about the effect of calcium arsenate upon some soils, but more information is needed to determine the influence of arsenic on other soils of the cotton belt.

The purpose of this study was to investigate the effect of calcium arsenate upon the productivity of several important soils of the cotton belt and to determine its probable influence upon the future soil status.

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[2]Director and agronomist, Mississippi Agricultural Experiment Station, Assistant Chemist, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agricutlure and Assistant in Soils, Mississippi Agricultural Experiment Station, respectively. F. H. Tucker (deceased) did the analytical work and H. C. Young and R. L. McGarr of the Bureau of Entomology and Plant Quarantine assisted in the field concrete plot work.

[3]Figures in parenthesis refer to "Literature Cited", p. 1028.

EXPERIMENTAL

SOILS

Seven important soil types, representing a large area of the cotton belt, were used in this study. The seven soils chosen were Cahaba fine sandy loam, Houston clay loam, Memphis silt loam, Norfolk sandy loam, Ruston fine sandy loam, Orangeburg fine sandy loam, and Sarpy fine sandy loam.

Cahaba fine sandy loam is a soil of the stream terraces in the Atlantic and Gulf Coastal Plain. The surface soil is gray, loose, friable, sandy loam; the subsoil is friable, reddish, sandy clay.

Houston clay loam is a well-drained soil of the Blackland Prairies occurring chiefly in Texas, Mississippi, and Alabama. The surface soil is black or nearly black clay loam; the subsoil is generally grayish-yellow or yellow clay; the substratum consists of marl or chalk.

Memphis silt loam is a well-drained soil developed from loess occurring on the bluffs on both sides of the Mississippi River southward from the vicinity of St. Louis almost to the Gulf of Mexico.

Norfolk sandy loam is a soil of the Atlantic and Gulf Coastal Plain of wide distribution and great agricultural importance. The surface soil is gray or light gray sandy loam; the subsoil consists of yellow, friable, sandy clay.

Orangeburg fine sandy loam occurs in the Atlantic and Gulf Coastal Plain in association with the Norfolk and Ruston soils. The surface soil is generally grayish-brown fine sandy loam; the subsoil is red, friable, sandy clay; and the substratum material is loose sand or fine sand.

Ruston fine sandy loam is a well-drained soil of the Atlantic and Gulf Coastal Plain with a surface soil of grayish-brown fine sand underlain by reddish-brown friable sandy clay subsoils with substratum of unconsolidated coastal plain materials. It is one of the most widely distributed soils of the coastal plain region. It has been leached of its bases and is generally medium or strongly acid throughout.

Sarpy fine sandy loam occurs in the first bottoms of the Mississippi River. It is a generally fertile soil composed of recent alluvium and ranks with the best cotton soils of the Mississippi delta region.

The seven soils vary greatly in texture, structure, reaction, and organic matter and should be representative of the most important soils in the eastern section of the cotton belt. Thirty inches of each soil type were removed in their relative position to seven 3 x 16 feet concrete plots, where each received different treatments of calcium arsenate.

TREATMENTS

Each soil type, located in seven different concrete plots, was given the following treatments: 0, 50, 100, 200, 400, 800, and 1,600 pounds of calcium arsenate per acre which was broadcast on the soil and mixed to a depth of 4 or 5 inches with shovels and hoes. Applications of calcium arsenate were made in the spring of 1935, a few days before the summer crops of cotton, corn, and soybeans were planted. Eight hundred pounds per acre of 4–8–4 fertilizer was applied to all plots each year. Each plot was replicated three times.

PROCEDURE

Germination and seedling counts were made upon cotton, corn, and soybeans. Then in the fall hairy vetch, Austrian peas, and oats, three important winter

cover crops, were planted on the seven plots of each soil type. Yields of all winter crops were obtained in 1935 and 1936 in order to measure the effect of the arsenicals on production. About 10 soil samples were taken from the top soil of each plot and after these were mixed into one composite sample, chemical and mechanical analyses and pH determinations were made.

RESULTS AND DISCUSSION

EFFECT OF CALCIUM ARSENATE UPON GERMINATION AND SEEDLINGS

An examination of Table 1 shows that neither germination nor seedlings of cotton on any soil type were affected by the 50-, 100-, or 200-pound arsenate application, and only the seedlings on Norfolk and Cahaba sandy loams were affected by the 400-pound treatment. When 800-pound applications were made, both germination and seedlings were greatly injured upon most of the soils, and when 1,600 pounds of arsenate were applied germination and viability were greatly reduced on all soil types except Houston clay loam. The living seedlings on Cahaba sandy loam were reduced from 77% to 5% by the 1,600-pound treatment. Although germination seems to be arrested by the heavier arsenate applications, the greatest toxicity occurs in the seedling stage, and the extent of this effect depends upon the nature of the soil.

The results with corn show that germination was not affected by calcium arsenate on any soil type and the seedlings were not affected by the lighter applications; however they were injured by the 800-pound and 1,600-pound applications, especially on the sandy soils. The viability of seedlings on Cahaba sandy loam was reduced from 90% to 10% by the 1,600-pound application.

Germination studies with soybeans show that its seed were only sensitive to heavy applications of calcium arsenate. The 800- and 1,600-pound applications reduced the percentage of germination in almost every soil, the germination of seed planted on Cahaba soil being reduced from 68% to 5%.

The effect of calcium arsenate upon germination and seedlings depends upon the nature of the plant as well as the soil. Neither germination nor seedlings of any plant were affected by the 50-, 100-, or 200-pound application, the larger of these applications being more calcium arsenate than most soils receive over a period of several years. The germination of cotton and soybean seed was greatly injured by the heavy arsenate treatments, but the germination of corn seed was not affected by any calcium arsenate treatment. The viability of cotton and corn seedlings was greatly reduced by the heavy arsenate applications; however, the injury varied with soil type. The seedlings on light, sandy soils were injured much more than those on heavy, clay soils. These results suggest that the harmful effect of calcium arsenate upon crops grown on light, sandy soils is because of the injury received in the seedling stage. Since plants are usually treated with calcium arsenate after their seedling stage, the possibility of injury at this stage is eliminated.

TABLE 1.—*Effect of calcium arsenate upon germination and seedlings.*

Soil type	Germination or seedlings	Percentages with applications of calcium arsenate in pounds per acre of						
		0	50	100	200	400	800	1,600
	Effect upon Cotton*							
Ruston fine sandy loam....	Germination	78	74	75	81	71	56	53
	Seedlings	72	69	70	72	62	35	23
Cahaba fine sandy loam ...	Germination	78	80	65	83	67	61	44
	Seedlings	77	75	61	80	53	34	5
Norfolk sandy loam.......	Germination	66	78	65	66	56	50	18
	Seedlings	55	71	54	55	25	12	4
Orangeburg fine sandy loam	Germination	75	69	68	66	68	64	51
	Seedlings	71	66	59	58	62	57	39
Memphis silt loam........	Germination	75	77	76	80	68	77	52
	Seedlings	70	71	72	75	62	67	33
Houston clay loam......	Seedlings	46	55	51	56	46	50	56
	Effect upon Corn							
Ruston fine sandy loam. ..	Germination	87	87	93	93	93	97	90
	Seedlings	87	87	93	93	83	73	53
Cahaba fine sandy loam ...	Germination	90	97	90	83	97	90	97
	Seedlings	90	93	90	73	73	53	10
Norfolk sandy loam.......	Germination	97	90	87	87	93	90	93
	Seedlings	97	83	83	87	77	60	40
Orangeburg fine sandy loam	Germination	100	87	100	90	87	87	83
	Seedlings	97	87	100	90	83	70	63
Memphis silt loam........	Germination	93	93	83	93	77	100	97
	Seedlings	90	93	83	90	73	93	87
Houston clay loam..... .	Seedlings	93	87	87	87	93	50	77
	Effect upon Soybeans†							
Ruston fine sandy loam ...	Germination	72	68	69	60	49	27	16
Cahaba fine sandy loam. ..	Germination	68	85	87	65	40	11	5
Norfolk sandy loam.......	Germination	73	68	73	71	67	56	37
Orangeburg fine sandy loam	Germination	60	33	39	41	40	39	41
Memphis silt loam.......	Germination	77	67	69	64	73	27	13
Houston clay loam	Germination	73	72	71	72	73	72	60

*Results are not reported on Sarpy fine sandy loam because seed on this soil were replanted. Only seedling counts were made on Houston clay loam.

†Seedling counts were not made on soybeans.

EFFECT OF CALCIUM ARSENATE UPON THE YIELD OF OATS, AUSTRIAN PEAS, AND VETCH

The data in Table 2 show that the yield of oats was not affected by the 50-, 100-, or 200-pound treatments, but that it was greatly reduced by the heavy applications of calcium arsenate. In 1935, soon after the arsenate was applied, yields on all soil types were affected by the 400-, 800-, and 1,600-pound applications, and there were 13 crop failures on these plots. In 1936, the yields on most soil types were still affected, but not nearly as much as in 1935. There was only one crop failure in the heavily treated plots. Oats grown on the sandy soils, Norfolk, Cahaba, Orangeburg, and Ruston, was more easily affected than that grown on Houston clay loam. However, both sandy

and clay soils were able to recuperate quickly from the toxic effect of calcium arsenate. In 1935, the 400-pound treatment reduced the

TABLE 2.—*Effect of calcium arsenate upon the yield of cover crops.*

Soil type	Year planted	Application of calcium arsenate in pounds per acre						
		0	50	100	200	400	800	1,600
		Yield of Oats, Lbs. Green Weight per Acre*						
Ruston fine sandy loam	1935	1,450	1,180	2,360	816	363	0	0
	1936	2,720	1,542	2,178	2,540	2,360	1,905	1,360
Cahaba fine sandy loam	1935	3,660	2,450	2,630	1,630	0	0	0
	1936	1,724	2,902	1,542	1,088	998	454	0
Norfolk sandy loam...	1935	2,990	3,900	2,270	454	181	0	0
	1936	2,430	2,810	1,815	2,360	2,270	—	635
Orangeburg fine sandy loam	1935	3,075	2,990	1,630	273	91	0	0
	1936	2,720	2,540	1,905	3,265	2,270	2,450	998
Houston clay loam....	1935	2,363	2,182	2,720	2,900	1,453	1,815	0
	1936	908	998	1,360	1,540	1,180	1,450	1,360
Sarpy fine sandy loam..	1935	454	540	726	454	0	0	0
	1936	818	1,180	1,180	908	546	546	272
		Yield of Austrian Peas, Lbs. Green Weight per Acre						
Ruston fine sandy loam	1935	6,710	9,150	7,260	4,350	3,270	1,360	181
	1936	4,355	2,270	2,810	4,900	5,080	3,538	2,270
Cahaba fine sandy loam	1935	10,800	6,710	3,260	6,160	3,180	0	0
	1936	3,900	4,720	3,630	4,080	3,900	1,815	0
Norfolk sandy loam...	1935	4,810	6,260	5,340	3,540	1,450	816	0
	1936	5,355	3,630	6,540	6,990	3,810	1,815	1,179
Orangeburg fine sandy loam..............	1935	8,180	7,980	10,400	8,890	12,250	3,810	2,720
	1936	3,540	4,355	2,902	3,082	2,270	2,902	1,230
Memphis silt loam....	1935	2,450	2,360	2,540	2,990	4,450	3,450	1,450
	1936	4,353	3,448	2,724	2,540	2,992	2,720	2,086
Houston clay loam....	1935	7,080	9,255	10,165	8,510	8,510	8,620	3,900
	1936	1,905	2,810	2,360	3,900	4,080	2,360	2,178
Sarpy fine sandy loam..	1935	10,708	12,600	10,600	8,440	3,260	908	0
	1936	8,620	10,160	8,345	12,975	2,630	3,084	635
		Yield of Hairy Vetch, Lbs. Green Weight per Acre						
Ruston fine sandy loam	1935	3,810	5,540	5,460	3,900	2,540	1,725	0
	1936	4,355	3,990	4,540	4,990	3,900	2,810	635
Cahaba fine sandy loam	1935	4,075	3,450	3,080	2,720	1,900	1,810	0
	1936	2,270	3,080	1,905	3,540	2,810	1,815	0
Norfolk sandy loam...	1935	6,800	7,520	9,530	2,260	544	0	0
	1936	2,630	3,450	2,540	3,355	2,410	1,088	0
Orangeburg fine sandy loam..............	1935	5,440	8,340	10,400	6,160	8,620	5,800	1,815
	1936	4,355	2,720	2,720	4,355	3,448	5,172	1,270
Memphis silt loam....	1935	2,720	2,540	2,720	1,810	3,260	1,540	454
	1936	4,355	4,080	2,992	4,170	3,720	2,720	1,815
Houston clay loam....	1935	6,540	10,400	9,255	8,350	4,710	5,620	908
	1936	1,995	2,080	2,810	2,360	2,088	2,720	1,088
Sarpy fine sandy loam..	1935	7,260	8,340	9,800	9,350	2,720	1,450	0
	1936	3,265	5,355	4,170	2,270	5,355	2,300	908

*Results are not given for Memphis silt loam because cattle damaged the crop in 1935.

yield of oats on Norfolk sandy loam from 2,990 to 181 pounds per acre; whereas, in 1936, it only reduced the yield from 2,430 to 2,270 pounds of green weight per acre. These data show that the toxic effect of arsenic is much greater immediately after the heavier applications are made and indicate that large amounts of soluble arsenic are lost, either by leaching or fixation, after a year.

The yield of Austrian peas was also reduced by the heavier arsenate treatments, but not as much as the yield of oats. In 1935, the Austrian peas on Ruston and Norfolk were injured by the 200-pound applications and those on Cahaba and Sarpy by the 400-pound application, but the yields on Orangeburg, Memphis, and Houston were not affected until 800- and 1,600-pound treatments were made. In 1936 hardly any yields were affected by arsenates, except on the 800- and 1,600-pound treated plots. These data also show that much of the toxic effect is lost one year after the arsenate was applied.

The yield of hairy vetch was also affected by the heavy treatments of calcium arsenate and the effect was very similar to that obtained with Austrian peas. In 1935, only the vetch on Norfolk and Cahaba sandy loams was affected by the 200-pound treatments, but yields on all other soils were affected by either the 400-, 800-, or 1,600-pound treatments. However, in 1936, the harmful effect was much less in every case. Even vetch on Norfolk and Cahaba soil was not affected except on the 400-, 800-, and 1,600-pound treated plots.

The data above indicate that both soil and crop determine the effect of applied arsenic. Of the cover crops studied, oats seems to be much more sensitive to arsenic than hairy vetch or Austrian peas. The light sandy soils, Ruston, Norfolk, Cahaba, and Sarpy, were more affected than the heavier Houston and Memphis soils. In most cases 400 pounds or more calcium arsenate were required to reduce materially the yield of oats, vetch, or peas. Although the yields on some soils were reduced by 200 and 400 pounds of arsenate in 1935, only those on the 800- and 1,600-pound plots were seriously affected in 1936. Both sandy and clay soils were able to dispose of large amounts of toxic arsenic over a period of one year. This indicates that even the most liberal application of calcium arsenate to cotton for insect control on the soils studied will not be great enough to affect a following crop of hairy vetch, oats, or Austrian peas.

EFFECT OF TIME UPON THE TOXICITY OF CALCIUM ARSENATE IN THE SOIL

Soil samples were taken from each plot soon after the calcium arsenate was applied in 1935 and similar samples were obtained one year later. Both were analyzed for water-soluble arsenic and the results are reported in Table 3. These data show that there was no great increase in the amount of water-soluble arsenic until 400 pounds of calcium arsenate per acre had been applied. Analyses from the 400-pound treated plots indicate that arsenic accumulates much faster in sandy than in clay soils, showing 40 ppm in Cahaba sandy loam, 60 ppm in Ruston and Orangeburg fine sandy loams, and only 9 ppm in Houston clay loam. These data suggest that the properties of Houston clay loam fix the arsenic into an insoluble state, whereas

those of Cahaba are unable to fix as much arsenic. One year later analyses from the same plots show that water-soluble arsenic in Cahaba sandy loam has been reduced from 40 to 16 ppm, while that in Houston clay loam has only been reduced from 9 to 8 ppm. The results show that great quantities of arsenic were lost from the sandy Cahaba with time, but very little was lost from the clay soil because it was probably held in an insoluble state. Analyses in 1935 from the 800-pound and 1,600-pound treated plots showed that great quantities of arsenic had accumulated in every soil. Even the water-soluble arsenic in Houston clay loam had increased to 200 ppm when 800 pounds of calcium arsenate were applied. The fixing capacity of the soil was probably saturated at some point between 400 and 800 pounds per acre, after which the rest of the applied arsenic remained water soluble.

TABLE 3.—*Parts per million of water-soluble arsenic in soils in 1935 and 1936.*

Soil type	Year	Application of calcium arsenate in pounds per acre						
		0	50	100	200	400	800	1,600
Ruston fine sandy loam	1935	2	5	9	8	60	190	450
	1936	Trace	2	2	4	8	14	250
Cahaba fine sandy loam	1935	Trace	4	4	11	40	120	300
	1936	Trace	2	4	4	16	80	87
Norfolk sandy loam	1935	Trace	2	2	14	30	80	400
	1936	Trace	Trace	2	6	16	24	60
Orangeburg fine sandy loam	1935	Trace	1	Trace	2	60	120	300
	1936	Trace	Trace	Trace	2	4	30	150
Memphis silt loam	1935	Trace	2	2	4	11	120	300
	1936	Trace	Trace	2	1	5	28	175
Houston clay loam	1935	Trace	2	4	7	9	200	270
	1936	Trace	2	4	4	8	80	100
Sarpy fine sandy loam	1935	1	8	12	30	100	275	500
	1936	Trace	4	4	5	40	80	100

In every case the water-soluble arsenic was much less in 1936 than in 1935 and only in the 800- and 1,600-pound plots was there enough arsenic remaining to cause serious injury to plants. These data substantiate those obtained with crop yields, which show that only those grown on the 800- and 1,600-pound treated plots were greatly affected in 1936.

The above results prove conclusively that great quantities of water-soluble arsenic are lost from the soil either by leaching or fixation. More of the applied arsenic accumulated immediately in the light than in the heavy textured soils, but more was also lost from the light soil during one year's time. This indicates that the arsenic applied to clay soils is lost immmediately, but that that applied to sandy soils is lost gradually. Since harmful quantities of arsenic did not accumulate until 400 pounds of calcium arsenate had been applied, and since most of this was lost in one year, it is doubtful that the present rate of dusting cotton will ever cause enough accumulation to be injurious to crops.

EFFECT OF PROPERTIES OF THE SOIL UPON ITS RESPONSE TO CALCIUM ARSENATE

In order to determine some reason for different effects of calcium arsenate upon various soils, chemical and mechanical analyses of each soil were made before calcium arsenate was applied. Determinations of total CaO, Fe_2O_3, Al_2O_3, MgO, P_2O_5, SiO_2, and clay content are shown in Table 4. Cahaba, Norfolk, and Ruston sandy loams —the soils most affected by calcium arsenate—were lower in iron, aluminum, calcium, and magnesium, those elements which have been thought to fix arsenic. The clay content was also much lower in these soils. Houston clay loam, the soil least affected by calcium arsenate, contained the highest amount of these elements. There is a high correlation between the presence of these elements and the effect of calcium arsenate upon the productivity of the soils. These results are in agreement with those obtained by other investigators. Zuccari (8) found that fixation of arsenic varied directly with the amount of iron in the soil, and he attributed a minor fixing power to aluminum and to calcium and magnesium carbonates. The authors have previously (4) concluded that arsenic fixation is principally due to the colloidal material, which contains a high iron content.

TABLE 4.—*Important physical and chemical characteristics of soils.*

Soil type	CaO %	Fe_2O_3 %	Al_2O_3 %	MgO %	P_2O_5 %	SiO_2 %	Clay* %	pH† %
Ruston fine sandy loam	0.20	1.35	5.79	0.25	0.063	91.25	8.4	5.58
Cahaba fine sandy loam	0.15	0.91	3.01	0.15	0.040	91.90	6.4	5.10
Norfolk sandy loam	0.19	1.29	4.73	0.18	0.076	93.55	10.4	4.79
Orangeburg fine sandy loam	0.28	2.39	9.44	0.34	0.066	84.77	26.8	5.44
Memphis silt loam	0.35	2.62	10.27	0.54	0.107	78.90	27.2	5.59
Houston clay loam	1.53	4.22	18.22	0.80	0.155	62.02	48.0	6.94
Sarpy fine sandy loam	1.00	2.62	11.07	0.60	0.209	76.85	24.0	6.02

*Determined by Boyoucos method (2).
†Determined by potentiometer method.

Therefore, it appears that the presence of a large amount of iron, aluminum, calcium, magnesium, and clay offset the toxic effect of arsenic, and those soils which are deficient in these elements will probably be most affected by heavy calcium arsenate treatments.

SUMMARY

Seven important soil types, representative of many soils in the cotton belt, were removed to concrete plots and treated with varying amounts of calcium arsenate. Different investigations were conducted on these soils, and the following conclusions drawn:

1. Neither germination nor seedlings were injured on any soil until 400 pounds per acre or more of calcium arsenate were applied. The greatest injury from the heavier applications occurred in the seedling stage and the extent of this injury depended upon the nature of the soil type. Cahaba, Norfolk, and Ruston sandy loams were more sensitive to arsenic than the other soils.

2. Crop yields from oats, Austrain peas, and hairy vetch planted immediately after the arsenic was applied and one year later show that yields were not affected except by heavy treatments and much of their toxicity was lost during one year's time. Oats seemed more sensitive to arsenic than Austrian peas and hairy vetch, but all crops grown on Norfolk, Ruston, and Cahaba sandy loams were injured more than those grown on heavier soils.

3. Large amounts of water-soluble arsenic did not accumulate in any soil until 400 pounds of calcium arsenate had been added, and then only in the sandy soils. Large quantities were lost from the heavily treated soils in one year's time.

4. Those soils which were most sensitive to arsenates (Norfolk, Cahaba, and Ruston sandy loam) contained the smallest amount of clay, iron, aluminum, calcium, and magnesium. Houston clay loam, the soil least affected by calcium arsenate, contained the largest quantity of these constituents.

5. Since hardly any damage to germination, seedlings, or crop yields occurred until an application of 400 pounds of calcium arsenate was made, and since large quantities of toxic arsenic were lost with time, the average application of calcium arsenate for insect control will probably never cause enough accumulation to injure crops usually grown on the soils used in this study.

LITERATURE CITED

1. ALBERT, W. B., and PADEN, W. R. Calcium arsenate and unproductiveness in certain soils. Sci., 73:622. 1931.
2. BOYOUCOS, G. J. Directions for making analysis of soils by the hydrometer method. Soil Sci., 43:225. 1936.
3. COOPER, H. P., PADEN, W. R., HALL, E. E., ALBERT, W. B., ROGERS, W. B., and RILEY, J. A. Effect of calcium arsenate on the productivity of certain soil types. S. Car. Exp. Sta., 44th Ann. Rpt.:28. 1931.
4. DORMAN, C., and COLEMAN, R. The effect of calcium arsenate upon the yield of cotton on different soil types. Miss. Agr. Exp. Sta. Scientific Paper No. 13, n. s. (unpublished).
5. GREAVES, J. E. The arsenic content of soils. Soil Sci., 34:355. 1934.
6. MORRIS, H. E., and SWINGLE, D. B. Injury to growing crops caused by the application of arsenical compounds to the soil. Jour. Agr. Res., 34:59. 1927.
7. REED, V. F., and STURGIS, M. B. Toxicity from arsenic to rice on flooded soils. Jour. Amer. Soc. Agron. 28:432. 1936.
8. ZUCCARI, G. The presence of arsenic as a normal element of soil. Gaz. Chim. Ital., 43:11, No. 4, p. 398–403. 1913.

STRAIN TESTS OF RED AND WHITE CLOVERS[1]

O. S. Aamodt, J. H. Torrie, and O. F. Smith[2]

THE use of adapted strains is essential for success with red and white clovers. This has been reported often with red clover but not for white clover. Frequently a shortage of domestic red clover seed in the United States results in large importations of unadapted foreign seed. Such a situation arose immediately following the World War and again in 1924, 1926, 1927, and 1937.

Numerous tests conducted at various experiment stations have shown, with few exceptions, that foreign strains of red clover are decidedly inferior to domestic strains. Among the earlier work was that of Moore (4),[3] which showed that European red clovers were not sufficiently hardy for Wisconsin conditions. During the years 1922 to 1929 tests were conducted at several experiment stations in cooperation with the U. S. Dept. of Agriculture. The results of these tests, which are reported by Pieters and Morgan (6), show that foreign red clovers, with few exceptions, are unadapted for the north central and eastern United States. A more detailed report of these studies at Wisconsin, New York, and Kentucky are given respectively by Delwiche (2), Wiggans (7), and Fergus (3). Their conclusions are essentially the same as given by Pieters and Morgan (6). From the results of tests of foreign red clovers in Illinois over a 15-year period Pieper and Burlison (5) state "the foreign seeds germinated well, but the stands though good the first year, were soon lost because of winterkilling and susceptibility to disease and insect injury. The true inferiority of the foreign strains, except those from Canada, showed up in their inability to produce a crop the second year".

Interest was renewed in this subject in 1937 as a result of large importations of foreign red clover seed, caused by a shortage of domestic seed. Aamodt, Delwiche, and Stone (1) stress the disadvantage of using foreign seed. They state that in years when winter injury is negligible foreign red clovers may produce a fair yield in the first but the second cut is usually small There is also the danger that domestic stocks will become contaminated by mechanical mixtures or cross pollination with foreign strains.

MATERIALS AND METHODS

In order to obtain more recent data on the relative performance of foreign and domestic clovers, under Wisconsin conditions, some 63 samples of red clover and 16 of white clover were planted in duplicate randomized plots in the spring of 1937 at the University Hill Farms. Similar plots of some 80 strains of red clover and

[1]Cooperative investigations of the Wisconsin Agricultural Experiment Station and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. Paper No. 146 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication September 29, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 1037.

20 of white clover were planted in the spring of 1938. The samples from states other than Wisconsin were obtained from A. L. Stone of the Wisconsin State Seed Testing Laboratory, and E. A. Hollowell of the U. S. Dept. of Agriculture. The Wisconsin samples were secured from farmers. The size of the plots was 5 by 10 feet, or 1/870 of an acre. The seed was sown in the spring without a nurse crop at a rate of 20 pounds per acre. The heavy rate of seeding used was to assure a good stand on all plots. Favorable weather for germination of the seed and for the early growth of the clover followed. The growth of annual weeds was kept in check by several mowings above the tops of the red clover plants during the summer.

In order to secure additional information, under conditions similar to those found on the average farm, in 1938 representative strains of foreign and domestic clover were sown in strips approximately 400 feet long and 7 to 14 feet wide. The field was first sown with Wisconsin Pedigree 38 barley. The clover seed was then sown on the surface of the soil at a rate of 12 pounds per acre with a wheelbarrow seeder, followed with a cultipacker seeder with timothy, at the rate of 5 pounds per acre.

To obtain a measure of the relative survival of the different strains, counts were made of the number of plants per unit area during the fall and early spring. The method used was to count the plants enclosed within a 6 by 6 inch square thrown at random on the plot. Six counts, two each by three readers, were taken for each plot. Estimates on the percentage coverage were made independently by three readers. Yields were taken on the first and second cut during the 50% bloom stage. The yield of weeds was recorded separately for the second cut. Dry weight determinations were based on samples of 700 to 1,000 grams.

EXPERIMENTAL RESULTS

RED CLOVER, 1937 PLANTING

The data in Table 1 give a summary by country of origin for the red clover samples planted in the spring of 1937. The number of plants is the total of six counts. For all the characters studied the difference between domestic and foreign strains were found to be highly significant.

The fall counts were taken on September 23, 1937, and the spring counts and percentage coverage on April 30, 1938, shortly after the start of spring growth. The date when each strain was approximately in the 50% bloom stage was recorded prior to the first cut in order to have some idea of the relative earliness of the strains. Yields were taken on the first cut during the period, June 10 to 30, and the second cut, August 4 to 15.

The data in Table 1 show that the number of plants for six counts both fall and spring, percentage coverage, and yield of hay for both first and second cuts were much lower for the European than for the domestic strains. The yield of weeds, however, is much higher for the European strains. The reduction in yield of the European strains is almost entirely the result of their inability to survive during the first year of growth. This probably was due to hot dry weather resulting in a heavy mortality of the plants weakened by leafhoppers. The differential summer-killing of foreign and domestic strains is shown in Fig. 1. This failure to survive the year of seeding probably has not been fully appreciated in the past and may have been reported as failure to survive the winters.

TABLE 1.—*Summary of data by country of origin for domestic and foreign red clover strains planted in the spring of 1937 at the University Hill Farms, Madison, Wisconsin*

Country	Number of samples	Total plants for six counts: FALL 1937 Number	FALL 1937 % U. S. av.	SPRING 1938 Number	SPRING 1938 % U. S. av.	Coverage, spring 1938 %	Coverage, spring 1938 % U. S. av.	50% bloom	Yield of dry hay, First cut: Tons per acre	First cut % U. S. av.	Second cut: Tons per acre	Second cut % U. S. av.	Total: Tons per acre	Total % U. S. av.	Yield of dry weeds, Second cut: Tons per acre	Second cut % U. S. av.
United States:																
Wisconsin	17	35	92	28	97	66	99	June 8	2.22	100	1.13	104	3.35	101	0.18	78
Other states	12	42	111	29	100	68	101	June 9	2.24	100	1.03	94	3.27	98	0.31	135
Average	29	38	100	29	100	67	100	June 9	2.23	100	1.09	100	3.32	100	0.23	100
Canada	7	39	103	33	114	72	107	June 22	2.64	118	0.91	83	3.55	107	0.40	174
Europe:																
France	1	16	42	5	17	5	7	June 9	0.51	23	0.17	16	0.68	20	0.60	361
Roumania	2	14	37	12	41	20	30	June 13	0.76	34	0.50	46	1.26	38	0.73	317
Czechoslovakia	1	13	34	11	38	15	22	June 15	0.87	39	0.27	25	1.14	34	0.64	279
Latvia	1	13	34	6	21	7	10	June 14	0.54	24	0.31	28	0.85	26	0.61	265
Wales	1	18	47	10	34	18	27	July 7	1.42	64	0.49	45	1.91	58	0.70	304
Hungary	8	15	39	11	38	15	22	June 13	0.74	33	0.29	27	1.03	31	0.83	361
Poland	9	10	26	8	28	9	13	June 14	0.57	26	0.20	18	0.77	23	0.89	387
Average	23	13	34	9	31	13	19	June 15	0.69	31	0.27	25	0.96	29	0.81	352
Chile	1	36	95	20	69	31	46	June 12	1.22	55	0.57	52	1.79	54	0.56	243
New Zealand	3	38	100	26	90	62	67	June 21	1.69	76	0.73	65	2.42	73	0.37	161

The average spring survival of the domestic and foreign red clovers was 75 and 69%, respectively, of their fall stand. This shows that although the winter of 1937–38 was not severe, some winter-killing occurred. In this respect the difference between domestic and European red clovers is not statistically significant.

The average yield of dry hay for the European strains for the first and second cut was 31 and 25%, respectively, of that produced by the domestic strains. This shows that although the yield of the European strains was much less than that of the domestic strains, the ratio between the two was similar for both cuts. The difference between the

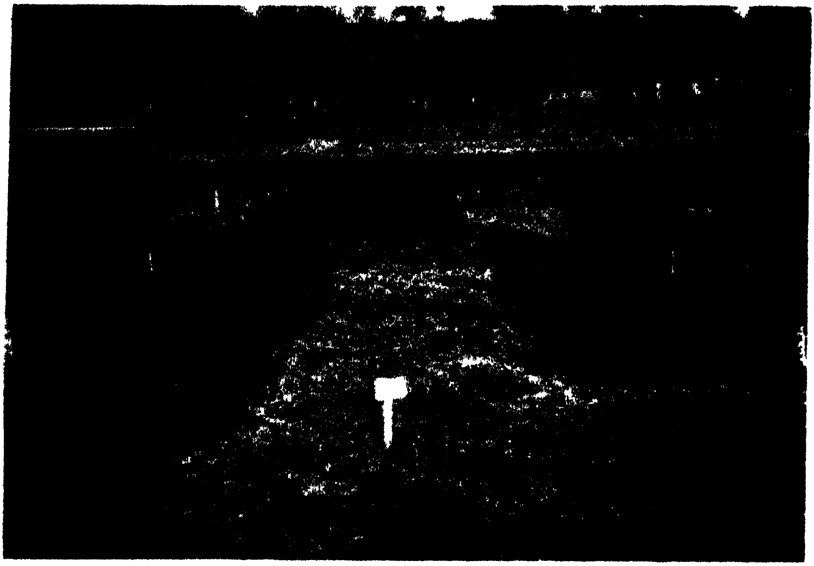

FIG. 1.—Differential summer-killing of foreign and domestic red clover strains during the first year's growth, summer of 1937. Plots with poor growth foreign strains, good growth domestic strains.

first and second cutting of European strains, when compared with domestic, is smaller than that commonly reported, probably because of the very favorable growth conditions throughout the 1938 season. The domestic strains were taller and flowered earlier and more profusely than the European strains. Several of the Canadian strains were of a semi-mammoth type and consequently bloomed later.

A strain from Chile had a fall and spring stand of 95 and 69%, respectively, of the average of the domestic strains. The total yield for both cuts was 54% of the domestic average. On the basis of this one strain from Chile the data indicate that red clovers from Chile are not adapted to Wisconsin conditions.

The domestic strains showed a greater vigor of growth. The average spring stand of the European strains was 31% of the average of the domestic strains, while the percentage coverage was only 19. Since the spring stand of the European strains was only 31% of the average

of the domestic strains, other things being equal, it would be reasonable to assume that the average yield of the foreign strains would be greater than 31% of the average of the domestic strains; for it is to be expected that the yield would not be directly proportional to the stand. This is indicated by the results obtained from four of the Wisconsin plots which had a relatively poor stand.

The average spring stand and percentage coverage of these four Wisconsin strains was 52 and 65, respectively, of the average of all of the United States strains, while the average yield of the first and second cuts was 86 and 85%, respectively, of the average of all the United States strains. One strain from Hungary, which was the best of the European strains, had a spring stand of 86%, spring coverage of 85%, and yield of first cut of 66% and yield of second cut of 50% of the United States average. This indicates that the yield of the Wisconsin strains with a poor spring stand was higher than would be expected if the yield was directly proportional to the stand, whereas, for the European strains, on the average, the yield was proportional to the stand.

Considerable interest is being shown throughout the country in long-lived, one-cut or mammoth types as compared to the medium or two-cut types. Several mammoth strains were included in the 1937 tests, consisting of Graham's Mammoth and five strains from Canada. Graham's Mammoth has been developed during the past 40 years by P. S. Graham, a farmer at Fennimore, Wisconsin. The 50% bloom stage for the mammoth types was approximately two weeks later than for the medium types Graham's Mammoth yielded 122, 98, and 114%, respectively, of the average of all domestic strains for the first, second, and combined cuts. The corresponding percentages for the average of the Canadian mammoth strains were 131, 85, and 116. These results indicate that in a season favorable for two cuts from mammoth clovers, the mammoth types will produce as large a yield as the medium types. When mammoth types are left to the 50% or full bloom stage of development before cutting as is the practice with the medium red clovers, a coarse stemmy hay is likely. If the mammoth is cut in the early bloom stage, which is usually about one week after the medium clover, a quality of hay equal to the mediums can be produced. In addition, considerably more growth is available for late summer or early fall and under certain conditions into the third or fourth years.

RED CLOVER, 1938 PLANTING

The year 1938 was an ideal clover year for domestic strains. The foreign red clovers, however, suffered severely from leafhopper damage during midsummer. The difference in the vigor of growth of the foreign and domestic strains was very noticeable at this time. September was very wet and cool which aided in eliminating the leafhoppers and allowed the foreign red clovers to recover from earlier damage by the leafhoppers. Counts made in the fall of 1938 on the 5 by 10 feet observation plots showed no significant difference in the relative stand of foreign and domestic strains. The percentage coverage and vigor of growth were estimated on October 28. The index for

vigor of growth was based on a scale of 1 (very weak growth) to 10 (very vigorous growth). The average percentage coverage and index of vigor of the foreign strains were 80 and 75%, respectively, of the average of the domestic strains. In the spring of 1939 the stand of all strains was very poor due to winter-killing.

The strains planted on the strips 400 feet long and 7 to 14 feet wide, survived the winter much better. The stand of all strains, with the exception of Graham's Mammoth, on approximately two-thirds of the field was very poor as a result of a heavy growth of volunteer barley in the fall of 1938. The good stand of Graham's Mammoth indicates that under the conditions of this experiment it has the ability to withstand adverse conditions much better than the medium red clovers tested.

The data given in Table 2 on the relative stand in the fall of 1938 and the spring of 1939, as well as the yield of dry hay, are for the portion of the field on which the stand was reasonably good. The stand counts, which were taken as described previously, except area, represent the number of plants found in 60 square feet. Five quadrats each 16 feet square were taken at random for all strains to give an estimate of the yield.

TABLE 2.—*Summary of data by strain for domestic and foreign red clovers planted in the spring of 1938 with a barley nurse crop at the University Hill Farms, Madison, Wisconsin.*

Strain	Plants per 60 square feet		Yield of dry hay, first cut, tons per acre		
	Fall, 1938	Spring, 1939	Clover	Timothy	Both
Wisconsin	130	75	0.95	0.66	1.61
Longhurst (Idaho)	147	42	0.66	1.05	1.71
Graham's Mammoth	151	156	1.86	0.37	2.23
New Zealand	120	3	0.10	1.63	1.73
Poland	109	16	0.30	1.10	1.40
Latvia	85	15	0.25	1.14	1.39
M. S. D.*	27	30	0.34	0.33	—

*M. S. D. Minimum difference between strains required to be significant at 5% level.

An analysis of the data shows that in the fall of 1938 the strain from Latvia was the only one which differed significantly in stand from the Wisconsin check. In the spring all three foreign strains and Longhurst's from Idaho had a significantly poorer stand than the Wisconsin check, while the stand of Graham's Mammoth was significantly better. Graham's Mammoth was the only strain which did not have a marked reduction in stand during the winter. The differences in stand are reflected by the large variation found between strains for yield of dry hay. The tonnage of dry clover hay produced by Graham's Mammoth was almost twice as great as that for the

Wisconsin check. The hay from the plots seeded to the foreign strains of clover consisted largely of timothy.

The authors made a trip through southwestern Wisconsin during the last week of June 1939. The only field of red clover and timothy visited which had a good stand of red clover was a field of mammoth red clover on the farm of P. S. Graham at Fennimore, Wisconsin. This observational evidence gives additional support to the experimental data, which indicates the superiority of Graham's Mammoth Clover over the medium clover type under adverse conditions.

WHITE CLOVER, 1937–38 PLANTINGS

The data on the percentage coverage of the white clover strains planted in conjunction with the 5 by 10 feet red clover plots are summarized in Table 3. The stand of all strains planted in the spring of 1937 was excellent in the spring and fall of 1938. Differential winter-killing, however, occurred during the winter of 1938–39. The percentage coverage of the strains from Poland, England, and New Zealand were very poor in comparison with those from Wisconsin, Sweden, and Denmark.

The strains planted in the spring of 1938 entered the winter in excellent condition. The strains from Louisiana and Mississippi were several inches taller and had a much more vigorous growth than the Wisconsin strains. The Louisiana and Mississippi strains, however, were killed out practically 100% by the winter of 1938–39. This difference in ability to survive the winter of 1938–39 is shown in Fig. 2.

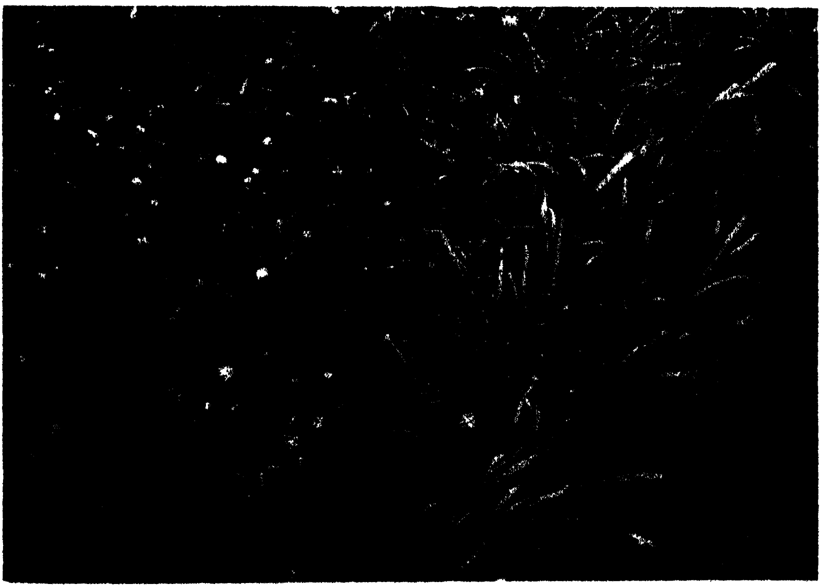

FIG. 2.—Differential winter-killing of white clovers during the winter of 1938–39. Wisconsin strain, plants alive (left); Louisiana strain, plants dead and weeds abundant (right).

The spring stand of the foreign strains, for the most part, was considerably poorer than that of the Wisconsin strains.

Two strains of white clover from Louisiana and one from Wisconsin were planted with the 400-foot strips of red clover. The stand of all three strains was excellent in the fall of 1938. The following spring, however, the Louisiana strains were dead, while the Wisconsin strain showed excellent growth.

TABLE 3.—*Percentage coverage by state or country of origin of domestic and foreign white clover strains planted in the spring of 1937 and 1938 at the University Hill Farms, Madison, Wisconsin.*

Country or state of origin	1937 planting				1938 planting		
	No. of strains	June, 1938	Oct., 1938	May, 1939	No. of strains	Oct., 1938	May, 1939
Wisconsin	2	100	100	100	3	90	58
Oregon	0	—	—	—	1	95	35
Louisiana	0	—	—	—	3	96	2
Mississippi	0	—	—	—	1	100	3
Sweden	3	100	100	85	2	73	28
Poland	1	100	100	35	1	85	30
Denmark	2	100	100	97	3	87	52
England	1	100	100	20	1	100	20
New Zealand	7	100	100	20	5	99	7

In the spring of 1937 plots were established to test the survival of white clover in bluegrass pasture under different fertility, clipping, and grazing treatments.[4] Three strains of white clover, Louisiana White, Corn Belt White, and Kent Wild White, were seeded at the rate of 2 pounds per acre on good bluegrass sod. Check plots to which no seed was applied were also included. The Louisiana White, which in the first year appeared better than the other strains on the grazed plots and as good as the others on the clipped plots, winter-killed almost completely during the winter of 1938–39. Corn Belt White had a significantly better stand than the Kent Wild White on the grazed plots, while on the clipped plots there was no significant difference between these two strains.

SUMMARY AND CONCLUSIONS

In order to determine the adaptability of various domestic and foreign strains of red and white clover under Wisconsin conditions, some 63 red clover and 16 white clover strains were planted in the spring of 1937 and 80 red and 20 white strains in 1938.

The 1937 results show that European red clovers are decidedly inferior to domestic strains in their ability to produce a good stand the year of seeding when drought and high temperatures prevail. As a result the hay crop in 1938 was poor both in yield and in quality of hay, the latter due largely to a high percentage of weeds.

[4]This pasture experiment is a cooperative one with H. L. Ahlgren, F. W. Tinney, and E. A. Hollowell. A more complete separate report will be made at a later date.

The average yield in tons of cured hay per acre in 1938 for red clover strains from different sources was Wisconsin 3.35, Canada 3.55, Hungary 1.03, Poland 0.77, all Europe 0.96, and all United States 3.32.

The superior performance of Graham's Mammoth indicates that this strain is hardier under adverse conditions than the medium or two-cut types.

Strains of white clover of different origins varied considerably in adaptability to Wisconsin conditions. White clover strains from Louisiana and New Zealand winter-killed almost completely in small plots, in large field plots, and in pasture plots during the winter of 1938–39.

LITERATURE CITED

1. AAMODT, O. S., DELWICHE, E. J., and STONE, A. L. Home-grown red clover seed best. Wis. Agr. Exp. Sta. Circ. 289. 1937.
2. DELWICHE, E. J. Tests of strains of red clover from various sources. Jour. Amer. Soc. Agron., 18:393-403. 1926.
3. FERGUS, E. N. Adaptability of red clovers from different regions to Kentucky. Ky. Agr. Exp. Sta. Bul. 318. 1931.
4. MOORE, R. A. Variety tests of clover. Wis. Agr. Exp. Sta. Ann. Rpt., 19:230–231. 1903.
5. PIEPER, J. J., and BURLISON, W. L. Foreign strains of alfalfa and red clover. What is their adaptability to Illinois. Ill. Agr. Exp. Sta. Bul. 431. 1937.
6. PIETERS, A. J., and MORGAN, R. L. Field tests of imported red clover seed. U. S. D. A. Circ. 210. 1932.
7. WIGGANS, R. G. Relative adaptability of red clover seeds of different origins. Cornell Univ. Agr. Exp. Sta. Bul. 463. 1927.

BOOK REVIEWS

LAND DRAINAGE AND RECLAMATION

By Quincey Claude Ayres and Daniel Scoates. New York: McGraw-Hill Book Company. Ed. 2. XI+496 pages, illus. 1939. $4.00.

IN WRITING this book, which obviously is intended to serve as a text for college students of agriculture, the authors have succeeded in producing a treatise which is both elementary and comprehensive. The book is mainly an exposition of engineering practices as they are applied to land surveys, drainage, irrigation, and the control of soil erosion. In order to orient these practices properly, discussion has been included on such subjects as soils, rainfall and run-off, drainage and conservation districts, and principles of law.

Those who approved the first edition of this book will undoubtedly approve the second. The introduction has been re-written and thereby improved. Additional space has been devoted to soil erosion and its control, evidently in response to the impetus currently given this subject by governmental agencies. The chapter on land clearing has been modified and condensed. Other and minor changes appear throughout the text.

The book should appeal to soil conservation workers who recognize themselves to be inadequately trained in the engineering phases of their work. (C. S. S.)

AN OUTLINE OF BRITISH CROP HUSBANDRY

By H. G. Sanders. New York: Macmillan Company. VIII+348 pages, illus. 1939.

THE author, who is a lecturer in agriculture in the University of Cambridge, makes it clear in his preface that this book is, as the title states, an outline and not in any sense a complete treatise on crop husbandry. Data and detail have been subordinated and general principles stressed, since, as the author says, principles are sometimes lost sight of in attention to the details of husbandry prevalent in any particular farming district.

The text deals with rotations, manuring, weed control, tillage and seedbed preparation, choice and treatment of seed, sowing, cultivation, and harvest as applied to various crops. In addition, a chapter is devoted to cost analysis. Some bibliography is given at the ends of chapters, the references being very largely British.

The subject matter seems well constructed and, although written entirely from the British viewpoint, American agriculture can learn much from a concise outline of the principles underlying British crop husbandry. (R. C. C.)

COMMON BRITISH GRASSES AND LEGUMES

By J. O. Thomas and L. J. Davies. New York: Longmans, Green and Co. 124 pages, illus. 1938. $2.20.

THIS little book does in an excellent manner exactly what its authors apparently intended it to do, namely, it serves as a guide to the identification of the common grasses and legumes in the field. While it was written to meet the needs of farmers, agricultural schools, and certain classes in agricultural colleges, it contains much material of immediate value to agronomists and botanists.

Following three chapters giving a discussion of the morphology of the common British grasses, useful plant characters, and a key to the vegetative characters, some 66 different species are definitely discussed, and, of these, 44 are illustrated. The rather accurate and excellent illustrations are so arranged as to face the text material describing each species, an excellent scheme which one soon comes to appreciate when using the book in the field or classroom.

Another useful and valuable feature about the book is that the authors have added to the section dealing with distribution and economic value much new material, particularly that having to do with new findings in pasture improvement through the use of the grasses and legumes. Agronomists should find the book very useful. (M.T.M.)

INTRODUCTION TO THE BOTANY OF FIELD CROPS

By J. M. Hector. Johannesburg: Central News Agency, Ltd. Vol. I, Cereals; Vol. II, Non-Cereals. LXV+1127 pages, illus. 1936–38. 3.10.0.

IN these two very useful volumes the author has assembled a great wealth of material on a wide variety of plants often classed as field crops. The cereals are dealt with in the first volume and in the second volume the author takes up 13 families which are classed as non-cereals yet contain the leading crop plants of the world. Each of these families is dealt with separately and has a key immediately following the general though brief discussion of the groups or subdivisions discussed. This is followed by an excellent bibliography arranged alphabetically by authors. The completeness and effectiveness of the bibliography is revealed as one uses the text and there finds new citations as well as the older standard or dependable ones.

The excellence of the first volume is continued on through the second volume and the author seems to have fulfilled his aim as ably explained in the introduction in presenting from a systematic and structural veiwpoint the entire plant, anatomically, histologically, and cytologically. The text material is nicely supplemented by many more or less excellent illustrations which are well placed. There are 88 tables which give the most useful data mentioned in the text discussion.

While the agronomist might be mostly interested in the first volume, the second volume is so valuable an addition that it really seems necessary. Both volumes are well printed and attractively

bound. They are broad in their scope and viewpoint and will surely find a place which has been only partly filled by other texts. The investigator, advanced student in agronomy, and the post-graduate should find these two volumes exceedingly useful and valuable. (M. T. M.)

ROOT NODULE BACTERIA AND LEGUMINOUS PLANTS

By E. B. Fred, I. L. Baldwin, and Elizabeth McCoy. Madison, Wis.: Univ. of Wisconsin Press. 40 pages. 1939. 50 cents.

THIS is a supplement to the first publication bearing the same title and published in 1932, and contains a list of papers published in this field from 1932 to 1938. A few important papers overlooked in the first report are also listed. As an added feature and in response to suggestions received by the authors, the index is supplemented by a list of the scientific names of all plants cited in the original monograph and by an author index.

RESEARCH ON GRASSLAND, FORAGE CROPS, AND THE CONSERVATION OF VEGETATION IN THE UNITED STATES OF AMERICA

By R. O. Whyte. Herbage Publication Series, Bulletin 26. Imperial Bureau of Pastures and Forage Crops, Aberystwyth, Wales. 113 pages, illus. 1939. 5s.

THIS bulletin gives an account of research in forage crops, range management, and the botanical aspects of soil conservation in the United States. A detailed summary is given of the research projects in the Division of Forage Crops and Diseases of the Bureau of Plant Industry, the Regional Pasture Research Laboratory, the Range Investigations of the Forest Service, the Research of the Soil Conservation Service, and of the state agricultural experiment stations. Reference is made to the studies in progess under the auspices of the U. S. Golf Association. A report of the Division of Plant Biology, Carnegie Institution of Washington, gives details of some researches on factor and function in adaptation, and on climax, succession, and conservation. (F.B.S.)

FELLOWS ELECT FOR 1939

LEONARD DAVID BAVER

LEONARD DAVID BAVER was born on a farm near Miamisburg, Ohio, December 8, 1901. He received his B.S. degree from Ohio State University in 1923 and the M.S. degree in 1926. He was granted the Ph.D. degree by the University of Missouri in 1929.

He is a member of the American Society of Agronomy, the Soil Science Society of America, the International Soil Science Society, and the American Geophysical Union.

Assistant in Agronomy, Ohio Agricultural Experiment Station, 1923–28; Research Fellow in Soils, University of Missouri, 1928–29; Associate Soil Chemist, Alabama Agricultural Experiment Station, 1929–31; Associate Professor of Soils, University of Missouri, 1931–37; Professor of Agronomy, Ohio State University, 1937–. During 1936, Senior Soil Conservationist in the Soil Conservation Service.

Member of numerous committees of the American Soil Survey Association, of the American Society of Agronomy, and of the Soil Science Society of America, and American representative of the Soil Physics Section at the last meeting of the International Society of Soil Science.

He has published numerous papers dealing with soil structure, consistency, porosity, genesis, and morphology, the colloidal properties of soils, soil organic matter and its effect on soil structure, erosion, and crop production. He made the earliest use in this country of the quinhydrone method for the determination of soil acidity and has developed an electro-thermal method for the determination of soil moisture.

MERLE TRUMAN JENKINS

MERLE TRUMAN JENKINS was born at Brookings, S. Dak., January 4, 1895. He received his B.S. degree from the Oregon State College in 1916, shortly thereafter, joined the U. S. Army. In 1919 he entered the United States Bureau of Plant Industry as scientific assistant in corn investigations, being advanced through the various grades to his present position of principle agronomist in charge of corn investigations in 1934. He received his M.S. degree from Iowa State College in 1925 and the Ph.D. degree from the same place in 1928.

From 1922 to 1934 he was in charge of the corn investigations co-operative between the Iowa Agricultural Experiment Station and the Bureau of Plant Industry, U. S. Dept. of Agri-

culture. During this time, Doctor Jenkins made notable contributions to the theory and practice of modern corn breeding, and also found time for genetic and physiologic research with corn, the results of which are reported in numerous papers.

Doctor Jenkins' most important agronomic contribution during this time probably was the development of the inbred lines of corn now used so extensively throughout the Corn Belt. One of these lines, L317B2, is probably the most resistant to drought of all lines so far developed, whereas his Iowa hybrid 939 is probably grown to advantage more widely than any other hybrid extant.

Since 1934 Doctor Jenkins' capability in handling his administrative responsibilities as leader of the Bureau's extensive corn investigations has permitted him to continue some personal research with corn which is bearing fruit.

Doctor Jenkins has taken an active interest in the affairs of the American Society of Agronomy for many years. He has organized symposia for the meetings, served on important committees, and been chairman of the Crops Section.

AUSTIN LATHROP PATRICK

Austin Lathrop Patrick was born in Scranton, Pa., August 23, 1889, and lived a part of his early life on a farm in northeastern Pennsylvania. He received his B.S. degree from Pennsylvania State College in 1913 and his M.S. degree in 1925. In 1931 he was granted the Ph.D. degree by Cornell University.

Doctor Patrick is a member of the American Society of Agronomy and of the Soil Science Society of America and of Sigma Psi, Phi Kappa Phi, and Gamma Sigma Delta honorary fraternities.

Scientist in Soil Surveys, U. S. Dept. of Agriculture, 1913–19; Assistant Professor, Associate Professor, and Professor of Soil Technology, Pennsylvania State College, successively, 1919–37. During this period he was in charge of the soil survey work in Pennsylvania and acted as Director of the short courses given at the College. From 1934 to 1937 he was "loaned" by the College to the Soil Erosion Service, later the Soil Conservation Service, and acted as Regional Director of the Service in Pennsylvania and was in charge of the development of the soil erosion experiment station at State College, Pa. From June 1937 to June 1939 Doctor Patrick was Chief of the Division of Watershed and Conservation Surveys of the Soil Conservation Service and since June 1939 has been acting as Assistant Chief of the Soil Conservation Service in charge of the divisions of surveys and project planning, with headquarters in Washington, D. C. He is the author of numerous publications in his field.

Doctor Patrick served as Secretary-Treasurer and as President of the American Soil Survey Association and was one of eleven soils men to be designated by Secretary of State Cordell Hull to represent the United States at the International Soil Science Congress in England recently. He has served on several committees of the American Society of Agronomy and was a member of the organizing committee of the Soil Science Society of America.

MINUTES OF THE THIRTY-SECOND ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE thirty-second annual meeting of the Society was held in the Roosevelt Hotel in New Orleans, Louisiana, November 22, 23, and 24. There were 670 registered at the meetings and over 700 in total attendance. In addition a large number of ladies accompanied their husbands and enjoyed the hospitality and beauty of New Orleans.

The general meeting of the Society was held on Thursday morning, November 23, with President R. J. Garber presiding. W. C. Lassiter, Editor of the PROGRESSIVE FARMER, spoke on "The Social and Economic Problems of Southern Agriculture", and M. J. Funchess, Dean of Agriculture at Alabama Polytechnic Institute, discussed "Agronomic Problems of the South". Both papers were well received and will appear in an early number of the JOURNAL.

The annual dinner was held on Thursday evening with the address of the President, "The Agronomist, His Profession, and an Example of Coordinated Research", as the feature of the occasion.

The Crops Section held programs on Breeding, Genetics and Cytology; Physiology, Morphology, and Taxonomy; and miscellaneous subjects. There were five sessions on each of the three groups of subjects and a total of 87 papers was presented. In addition there were round table discussions and conferences.

The Soil Science Society held 14 sectional meetings with programs on soil physics, soil chemistry, soil fertility, soil genesis, morphology and cartography, and soil technology. There were 88 papers presented in addition to 7 presented at a joint session with the Crops Section. A general soils program was held on Thursday afternoon with the presentation of 5 papers.

The Auditing Committee appointed by President Garber consisted of Dr. F. B. Smith and Dr. H. H. Laude. The Nominating Committee consisted of President Garber as chairman and Dr. F. D. Keim, Dr. W. A. Albrecht, Prof. H. C. Rather, and A. M. O'Neal.

FELLOWS

Vice-president Alway announced the Fellows Elect and presented the certificates. Those elected were Dr. L. D. Baver, Dr. M. T. Jenkins, and Dr. A. L. Patrick. (See pages 1041 to 1042.)

OFFICERS' REPORTS

REPORT OF THE EDITOR

WHEN Volume 31 of the JOURNAL is completed it will contain approximately 1,100 pages and will present 108 papers, 22 notes, and 23 book reviews, in addition to numerous miscellaneous items that appear under the general heading of "Agronomic Affairs". At this writing 18 papers have been returned for one reason or another and sufficient material is in hand for the January 1940 number. Thus, we come to the end of another year of JOURNAL publication with what we regard as a satisfactory state of affairs, at least from an editorial point of view.

The Treasurer's report will show our financial status which we believe is also satisfactory, considering that extra demands were made upon the finances of the Society with the publication of the cumulative index for Volumes 21 to 30, inclusive, and with the allotment to the Editor of a small sum, shared by the Soil Science Society, for the employment of a part-time editorial clerk. Incidentally, this part-time assistance and the Editor's own item are now covered very largely by the advertising income of the JOURNAL. Practically all contracts for advertising have already been renewed for 1940 and one or two new advertisers are considering the JOURNAL for next year, so we would urge especially that you "mention the JOURNAL to advertisers".

The cumulative index has been fairly well received, but we have not yet recovered in its sale the entire cost of publication. We believe everyone who keeps a complete file of the JOURNAL will eventually want this useful tool which may be obtained for the very nominal sum of $1.00.

A new undertaking for your Editor this past year was the handling of the 1938 PROCEEDINGS of the Soil Science Society. The procedure for the editing and publishing of this volume had been so well conceived and so carefully worked out by Doctor Bradfield and his associates prior to our taking over last fall that it was largely a matter of following the lines laid down by these men. We are conscious, however, of certain shortcomings in the handling of Volume 3 of the PROCEEDINGS, some of which were beyond our control, to be sure; but we are hopeful for more prompt and more satisfactory service in this direction with increasing experience.

You may be interested in learning something about the magnitude of the sales of the several agronomic publications entrusted to our care. Almost every mail brings in orders for one or more of these publications and of course we are constantly being called upon to supply back numbers of the current volume of the JOURNAL to new members of the Society or to send the PROCEEDINGS to some one who paid his dues to the Soil Science Society. Just for your information, here are the figures since January 1st: Seven sets of the PROCEEDINGS of the First International Society of Soil Science; 9 bulletins of the Soil Survey Association; 244 orders for the indexes to the JOURNAL; 285 orders for back numbers of the JOURNAL; and 315 orders for different volumes of the PROCEEDINGS of the Soil Science Society.

Further correspondence was carried on during the year with the Editorial Advisory Committee with reference to enlarging the personnel of that committee and to expanding its functions still further as a review board for contributions to the JOURNAL. The services of the present members of the committee have been utilized throughout the year, along with those of others, in reviewing papers, but we feel that the time has come when the editorial policies of the JOURNAL, in so far as they have to do with the acceptance or rejection of papers, should be placed upon a somewhat more rigid procedure than now prevails. This is presumably a matter for the Editorial Advisory Committee and the Executive Committee to work out.

We are a bit concerned as to what the unsettled conditions abroad may do to our large and profitable foreign circulation. Thus far there have been no serious reverberations, but it would not be at all surprising to see many cancellations with the expiration of present subscriptions; in fact it will be most surprising if we do not suffer serious inroads in our foreign subscriptions. There are many men working in the various fields of agronomy in this country who are not yet members of this Society or subscribers to the JOURNAL. A little home missionary work would do much to offset here at home what we are likely to loose abroad.

A recent correspondent expressed regret that the JOURNAL did not have more personal items about the goings and comings of agronomists. To show that he was sincere in the matter, he submitted several items from his own institution which will appear in an early number of the JOURNAL. Doubtless we have been remiss in not encouraging more "letters to the Editor", and it goes without saying that we would welcome more news items. To stimulate anew interest in this section of the JOURNAL, we shall soon ask each Department of Agronomy to designate someone in their organization who will assume responsibility for seeing that we are kept informed on changes in personnel and in events of interest to other agronomists that transpire within their group.

On behalf both of the Society and of the JOURNAL, we would express our appreciation of the very efficient discharge of the multitudinous duties of his office by our Secretary-Treasurer, Doctor G. G. Pohlman. The JOURNAL could survive for sometime without an Editor, but the affairs of the Society would bog down very quickly without the constant and close supervision of the Secretary's office which we have enjoyed during the past year.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society since the last annual report are briefly summarized as follows:

Membership last report		1,230
New members, 1939	86	
Reinstated members	63	
Total increase	149	
Dropped for non-payment of dues	127	
Resigned	28	
Died	7	
Mail returned unclaimed	12	
Total decrease	174	
Net decrease		25
Membership, October 31, 1938		1,205

The subscription list has increased during the year as shown by the following figures:

Subscriptions, last report		660
New subscriptions, 1939	129	
Subscriptions dropped	102	
Net increase		27
Subscriptions, October 31, 1939		687

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscriptions
Alabama	10	1
Arizona	8	3
Arkansas	9	4
California	40	10
Colorado	17	1
Connecticut	9	2
Delaware	4	0
District of Columbia	87	5
Florida	17	3
Georgia	16	0
Idaho	8	1
Illinois	45	9
Indiana	25	3
Iowa	36	2
Kansas	42	3
Kentucky	10	4
Louisiana	19	4
Maine	5	1
Maryland	17	5
Massachusetts	11	4
Michigan	21	5
Minnesota	25	5
Mississippi	12	1
Missouri	17	4
Montana	8	5
Nebraska	31	3
Nevada	2	1
New Hampshire	2	0
New Jersey	15	4
New Mexico	5	2
New York	47	11
North Carolina	16	5
North Dakota	12	1
Ohio	47	4
Oklahoma	11	5
Oregon	10	3
Pennsylvania	18	6
Rhode Island	7	0
South Carolina	14	2
South Dakota	7	1
Tennessee	14	2
Texas	49	11
Utah	10	6
Vermont	3	0
Virginia	23	3
Washington	20	4
West Virginia	10	1
Wisconsin	31	2
Wyoming	7	1
Alaska	0	1
Hawaii	8	8
Philippine Islands	1	2
Puerto Rico	3	2
Africa	4	28

	Members	Subscriptions
Argentine	8	10
Australia	1	26
Brazil	0	5
British Guiana	0	1
British West Indies	1	1
Canada	14	39
Ceylon	0	3
Chile	2	1
China	3	13
Columbia	1	0
Costa Rica	1	0
Cuba	1	4
Denmark	2	0
Dutch East Indies	0	6
Egypt	1	3
England	3	13
Estonia	0	1
Fed. Malay States	1	3
Fiji	0	0
Finland	0	5
France	1	11
Germany	2	7
Greece	2	1
Holland	0	4
Honduras	1	1
Hungary	0	0
India	5	20
Indochina	0	1
Ireland	0	2
Italy	0	12
Japan	6	76
Jugoslavia	1	1
Mauritius	0	1
Mesopotamia	0	0
Mexico	1	0
New Zealand	0	6
Norway	0	2
Palestine	2	0
Persia	1	0
Peru	2	1
Poland	2	1
Portugal	1	4
Roumania	0	1
Scotland	2	1
Siam	2	1
Spain	0	1
Sweden	0	2
Switzerland	1	1
Turkey	2	2
Uruguay	1	0
U. S. S. R.	6	95
Venezuela	1	2
Wales	0	3
	1,026	598

The number dropped for non-payment of dues is about the same as in 1938 as is also the number resigned. A large number of the subscribers who have been dropped are from China, Japan, and Russia. There are 179 members and 89 subscribers who have not yet paid their 1939 dues. We hope that they will soon pay

their dues and continue in the Society. There have been a number of members whose mail has been returned. These are principally foreign members, although a few are in the United States.

The decrease in membership is largely the result of a much smaller number of new members than last year. Apparently we have not given enough attention to this part of the work. A number of members have been very active in securing new members. The Society appreciates your cooperation in helping in this way.

The number dropped for non-payment of dues seems too high. I would appreciate any suggestions as to how the old members can be retained. A few have criticized the Society for dropping their names from the rolls without sufficient notice. However, no one has been dropped who has not been at least a year in arrears. During this time at least two notices have been sent.

At times during the past year it seemed that the Secretary's office was pretty slow in attending to orders and answering correspondence. However, you were very patient and eventually we got things straightened out. I appreciate your cooperation. I also wish to thank those in charge of the various programs for the promptness and order in which they sent in the programs. This was especially helpful in speeding up the delivery of the programs to the members.

Respectfully submitted,
G. G. Pohlman, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year, November 1, 1938, to October 31, 1939.

RECEIPTS

Miscellaneous	$2,820.84
Advertising income	783.20
Reprints sold	1,796.82
Journals sold	214.43
Subscriptions, 1939	2,345.00
Subscriptions, 1938	65.10
Subscriptions, 1939 (new)	696.32
Subscriptions, 1940 (advanced)	180.00
Dues, 1939	4,310.16
Dues, 1938	485.75
Dues, 1939 (new)	417.26
Dues, 1940 (advanced)	91.50
Index	172.08
Miscellaneous (S.S.S.A.)	75.50
Sale of Soil Survey Bulletins (Marbut Memorial Fund)	141.05
Sale of Proceedings, Vol. I (1936)	87.50
Sale of Proceedings, Vol. II (1937)	398.76
Dues and subscriptions S.S.S.A. (old) 1939	2,203.16
Dues and subscriptions S.S.S.A. (new) 1939	292.56
Dues and subscriptions S.S.S.A. (advanced) 1940	13.50
Membership only S.S.S.A., 1939	20.50
Sale of Proceedings First International Congress of Soil Science	95.75
Fees, I.S.S.S., 1939	704.56
Fees, I.S.S.S., 1939 (new)	107.50
Fees, I.S.S.S., 1938	40.00
Fees, I.S.S.S., 1940 (advanced)	9.50
Total receipts	$18,568.30
Balance in cash, November 1, 1938	2,723.64
Total income	$21,291.94

DISBURSEMENTS

Printing the Journal, cuts, etc.		$ 9,707.13
Salary, Business Manager and Editor		750.00
Postage, Business Manager and Secretary		184.81
Printing, miscellaneous		317.85
Express on Journal and Proceedings		18.72
Mailing clerk and stenographer		769.39
Refunds, checks returned, etc.		111.42
Miscellaneous, expenses annual meetings, etc.		3,266.26
S.S.S.A. expenses, printing Proceedings, etc.		3,408.53
I.S.S.S. expenses, fees to Dr. Hissink, etc.		784.69
Total disbursements		$19,318.80
Total income	$21,291.94	
Less total disbursements	19,318.80	
Balance in checking account Oct. 31, 1939	$ 1,973.14	
Balance in trust certificate	267.71	
Balance in savings bonds	2,250.00	
Total assets		$ 4,490.85

Respectfully submitted,
G. G. POHLMAN, *Treasurer.*

AUDITING COMMITTEE

THE Committee examined the books and found them to be in order and the accounts to be correct as reported by the Treasurer.

Respectfully submitted,
H. H. LAUDE
F. B. SMITH, *Chairman*

OTHER COMMITTEE REPORTS

EDITORIAL ADVISORY COMMITTEE

THE Editorial Advisory Committee made the following recommendation: That it be replaced by an Editorial Board made up as follows: An Editor, an Associate Editor in Crops and an Associate Editor in Soils, and from three to five Consulting Editors in both soils and crops.

The Editor and the Associate Editor in Crops and Associate Editor in Soils shall be selected by the Executive Committee of the Society. They shall be reappointed from year to year, but their tenure shall whenever possible be extended over several years. The Consulting Soils Editors and the Consulting Crops Editors shall be specialists in the various subdivisions of their respective subjects. They shall be selected by the Associate Editor in charge of the respective field.

All papers submitted for publication in the JOURNAL shall be directed to the Editor. He in turn shall refer all papers dealing predominantly with soils to the Associate Editor in Soils and all papers dealing predominantly with crops to the Associate Editor in Crops. The Associate Editors shall, with the aid of their respective Consulting Editors, review the papers submitted to them and shall make such recommendations to the Editor as they see fit regarding their suitability for publication in the JOURNAL.

The Editor shall, as in the past, be responsible for preparing the manuscripts for the printer and for handling all correspondence with the authors of papers.

R. J. GARBER J. D. LUCKETT
MERLE T. JENKINS I. L. BALDWIN
RICHARD BRADFIELD, *Chairman*

BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE committee has compiled a bibliography of 82 titles of the more important contributions on the methodology of and interpretation of results of field plat experiments, either reported since or not included in the revised bibliography published in the JOURNAL (Vol. 25: 811-828, 1933; and the additions in Vol. 27: 1013-1018, 1935; Vol. 28: 1028-1031, 1936; Vol. 29: 1042-1045, 1937; Vol. 30; 1054-1056, 1938).

ADDITIONS TO BIBLIOGRAPHY ON STANDARDIZATION OF FIELD EXPERIMENTS

AHLGREN, H. L., BOHSTEDT, G., and AAMODT, O. S. Problems in evaluating pastures in relation to other crops. Jour. Amer. Soc. Agron., 30:1020-1029. 1938.

AKEMINE, M. Analysis of variance as applied to the inter-varietal difference of sterility in paddy rice. Jour. Sapporo Soc. Agr. and For. 31:1-14. 1939. (Japanese with Eng. abs.).

ARCENEAUX, G., and STOKES, I. E. Studies of gaps in sugarcane rows and their effect upon yield under Louisiana conditions. U. S. Dept. Agr. Cir. 521. 1939.

ARCENEAUX, G., STOKES, I. E., BELCHER, B. A., and GIBBENS, R. T., JR. Border competition in sugarcane variety tests under Louisiana and Georgia conditions. Internatl. Soc. Sugar Cane Technol. Cong. Proc., 6:403-420. 1938.

———. A study of the relation between size of field sample and experimental errors of juice analysis and sugar-yield determinations in connection with sugarcane variety tests. Internatl. Soc. Sugar Cane Technol. Cong. Proc., 5:744-759. 1938.

BÄR, A. L. S. Interpretatie van proefveld-resultaten. (Arrangement of field experiments.). Landbouwk. Tijdschr. Wageningen 51:229-246. 1939. (Eng. abs.).

BATEN, W. D. Formulas for finding estimates for two and three missing plots in randomized block layouts. Michigan Expt. Sta. Tech. Bul. 165. 1939.

BAVER, L. D., and BRUNER, F. H. Rapid soil tests for estimating the fertility needs of Missouri soils. Missouri Expt. Sta. Bul. 404. 1939.

BJERKE, B. Sammenregning av observasjoner.—II, Det. tredimensjonale tilfelle. (Notes on the mathematical treatment of observations.—II, The three dimensional case.) Meld. Norges Landbr. Hisk 18:98-111. 1938.

BLAIR, I. D. Studies of intensity of plant population in wheat fields. New Zeal. Jour. Sci. and Technol. 20:156A-163A. 1938.

BORDEN, R. J. A modern statistical analysis for field experiments. The analysis of variance for simple factorial experiments. Hawaii. Planters' Rec. 43:73-114. 1939.

———. Studies in experimental technique. Selection of layout: Blocks versus Latin squares. Hawaii. Planters' Rec. 43:7-10. 1939.

———. Studies in experimental technique: Plot arrangement. Internatl. Soc. Sugar Cane Technol. Cong. Proc., 6:733-744. 1938.

BOURNE, J. B. The importance and use of appropriate assumed means in collating field experimental results statistically. Trop. Agr. (Trinidad) 15:247-258. 1938.

BROWN, B. E., ZIMMERLEY, H. H., HOUGHLAND, G. V. C., REDIT, W. H., and SCHOENLEBER, L. G. Further studies on the placement of fertilizer for potatoes. Amer. Potato Journ. 16:81-93. 1939.

BUROS, O. K. (ed.). Research and statistical methodology: Books and reviews 1933-1938. Rutgers Univ. Press. New Brunswick. 1938.

CAROLUS, R. L. The use of rapid chemical plant nutrient tests in fertilizer deficiency diagnoses and vegetable crop research. Virginia Truck Expt. Sta. Bul. 98. 1938.

CHAN-CHOONG, P. A. Testing large numbers of rice varieties by the quasi-factorial method. Agr. Jour. Brit. Guiana 10:78-88. 1939.

CHRISTIDIS, B. G. Further studies on competition in yield-trials with cotton. Emp. Jour. Expt. Agr. 7:111-120. 1939.

CLARK, A., and LEONARD, W. H. The analysis of variance with special reference to data expressed as percentages. Jour. Amer. Soc. Agron. 31:55-66. 1939.

COCHRAN, W. G. The omission or addition of an independent variate in multiple linear regression. Jour. Roy. Statis. Soc., Sup. 5:171–176. 1938.

CORNISH, E. A. Factorial treatments in incomplete randomized blocks. Jour. Austral. Inst. Agr. Sci. 4:199–203. 1938.

COSTELLO, D. F., and KLIPPLE, G. E. Sampling intensity in vegetation surveys made by the square-foot density method. Jour. Amer. Soc. Agron. 31:800–810. 1939.

CRIST, J. W. Intraclass correlation for horticultural research. Proc. Amer. Soc. Hort. Sci. 36:347–350. 1938.

CULLEY, M. The decagon for vegetation studies. Jour. Forestry 37:492–493. 1939.

CUMINGS, G. A., and HOUGHLAND, G. V. C. Fertilizer placement for potatoes. U. S. Dept. Agr. Tech. Bul. 669. 1939.

DABRAL, B. M., and CHINEY, S. S. A note on border effects in manurial experiments on cotton at Sakrand during 1935-36. Ind. Jour. Agr. Sci. 8:629–635. 1938.

DAVIS, J. F. A comparison between yields calculated from the grain-straw ratio and those calculated from small-cut-out areas. Jour. Amer. Soc. Agron. 31: 832–840. 1939.

DAWSON, C. D., and DORN, M. V. Plant chemiculture; a guide to experiments in growing plants without soil. Los Angeles, Calif., 3 ed. 1939.

DAWSON, C. D. R. An example of the quasi-factorial design applied to a corn breeding experiment. Ann. Eugen. Cambridge 9:157-173. 1939.

DAY, B. B., and AUSTIN, L. A three-dimensional lattice design for studies in forest genetics. Jour. Agr. Res. 59:101–119. 1939.

FISHER, R. A. Statistical methods for research workers. Edinburgh and London, Oliver and Boyd, 7. ed. 1938.

FISHER, R. A., and YATES, F. Statistical tables for biological, agricultural, and medical research. London, Oliver and Boyd. 1938.

FRANKEL, O. H., and HAIR, J. B. Analytical yield investigations on New Zealand wheat.—III, Nine years' observations on two varieties. New Zeal. Jour. Sci. and Technol. 20:244A–259A. 1938.

GARNER, F. H., SANDERS, H. G., HAY, G. B., and KEMSLEY, W. F. F. Experiments on the spacing of sugar beet.—I-III. Jour. Agr. Sci. 29:48–75. 1939.

GOULDEN, C. H. Methods of statistical analysis. New York, John Wiley & Sons, Inc. 1939.

HARRINGTON, J. B. The number of replicated small plat tests required in regional variety trials. Jour. Amer. Soc. Agron. 31:287–299. 1939.

HARTMAN, J. D. Rapid soil tests used on plots of a vegetable soil acidity experiment. Soil Sci. Soc. Amer. Proc. 3: (1938) 138-145. 1939.

HASEL, A. A. Sampling error in timber surveys. Jour. Agr. Res. 57:713–736. 1938.

HOOVER, M. M., and WHITE, T. W. Integration of agronomy-range management and nursery phases of grass work. Rpt. Proc. Regional Agronomists & Range Examiners Conf. (U. S. D. A. Soil Cons. Serv.), Washington, D. C., 89–101. 1938.

HUDSON, H. G. Population studies with wheat.—I, Sampling. Jour. Agr. Sci. 29: 76–110. 1939.

JEFFREYS, H. Random and systematic arrangements. Biometrika 31:1–8. 1939.

KERR, H. W. Notes on plot technique. Internatl. Soc. Sugar Cane Technol. Cong. Proc. 6:764–778. 1938.

KERR, H. W., and STIEGLITZ, C. R. VON. Some studies in soil sampling technique. Technol. Commun. Bur. Sugar Expt. Sta., Queensland 9/10:205–217. 1938.

KRISTENSEN, M. K. Ueber das feldversuchswesen in Dänemark und seine bedeutung für die praktische landwirtschaft. Forschungsdienst (Neudamm) 6:376–390. 1938.

LECLERG, E. L. Relative efficiency of quasi-factorial and randomized-block designs of experiments concerned with damping-off of sugar beets. Phytopath. 29:637–641. 1939.

MACDONALD, D., FIELDING, W. L., and RUSTON, D. F. Experimental methods with cotton.—I, The design of plots for variety trials.—II, A study of the effects of seed rate and time of thinning on the development and yield of cotton plants in hand-planted cotton trials. Jour. Agr. Sci. 29:35–47, 418–430. 1939.

MAHALANOBIS, P. C. A review of the application of statistical theory to agricultural field experiments in India. Proc. Crops & Soils Wing Bd. Agr. and Anim. Husb., India 2:200–215. 1937.

MAHONEY, C. H., and BATEN, W. D. The use of the analysis of covariance and its limitation in the adjustment of yields based upon stand irregularities. Jour. Agr. Res. 58:317–328. 1939.

METHESON, M. A comparison of various field ecological light measuring instruments, and a further contribution to our knowledge of the Edar Hecht. photometer and the Livingston radio atmometer. So. Afr. Jour. Sci. 35:263–273. 1938.

MOFFATT, J. R. Agricultural methods adopted in the Rothamsted classical and modern field experiments. Emp. Jour. Expt. Agr. 7:251–260. 1939.

MOSER, F. The adaptability of rapid chemical tests for use in determining the nutrient needs of South Carolina soils. Jour. Amer. Soc. Agron. 31:188–199. 1939.

MURRAY, W. G., ENGLEHORN, A. J., and GRIFFIN, R. A. Yield tests and land valuation. Iowa Expt. Sta. Res. Bul. 252. 1939.

NORTON, E. A. Soil conservation survey handbook. U. S. Dept. Agr. Misc. Pub. 352. 1939.

PAGE, H. J. The uses of statistics in field experiments with rubber trees. Part II. Plant. Chron. 34:174–178. 1939.

PATERSON, D. D. Statistical technique in agricultural research. A simple exposition of practice and procedure in biometry. New York, McGraw-Hill Book Co. 1939.

PRILLWITZ, P. M. H. H. De berekening van het minimum aantal theeplanten in toetsingsproeven. (On the number of plants in testing-experiments with tea.) Arch. Theecult. Ned.-Ind. 8:1–8. 1934.

PUGH, B. M., and KHAN, L. A. The use of statistical methods in cultivation experiments. Allahabad Farm. 12:196–205. 1938.

REMUSSI, C. Aplicación del análisis de la variancia a los ensayos comparativos de rendimiento. (Application of the analysis of variance to comparative yield tests.) Rev. Argentine Agron. 5:254–283. 1938.

SALMON, S. C. Unbalanced arrangements of plats in Latin squares. Jour. Amer. Soc. Agron. 30:947-950. 1938.

SAVUR, S. R. A note on the arrangement of incomplete blocks, when $k=3$ and $\lambda=1$. Ann. Eugen. Cambridge 9:45–49. 1939.

SCHREINER, O., and ANDERSON, M. S. Laboratory and field methods for determining fertilizer requirements of soils. Internatl. Soc. Sugar Cane Technol. Cong. Proc. 6:650–663. 1938.

SINGH, B. N., and DAS, K. Percentage frequency and quadrat size in analytical studies of weed flora. Jour. Ecol. 27:66–77. 1939.

SNEDECOR, G. W. Statistical methods applied to experiments in agriculture and biology. Ames. Iowa, Collegiate Press, Inc. (rev.). 1938.

SPRAGUE, G. F. An estimation of the number of top-crossed plants required for adequate representation of a corn variety. Jour. Amer. Soc. Agron. 31:11–16. 1939.

STEVENS, W. L. The completely orthogonalized Latin square. Ann. Eugen. Cambridge 9:82–93. 1939.

SYKES, F. J., and BROWN, G. F. New developments in agronomic practices. Rpt. Proc. Regional Agronomists & Range Examiners Conf. (U. S. D. A. Soil Cons. Serv.), Washington, D. C. 26–38. 1938.

TANG, P. C. The power function of the analysis of variance tests with tables and illustrations of their use. Statis. Res. Mem., Dept. Statis. Univ. London 2:126–149. 1938.

THOMAS, W., and MACK, W. B. Control of crop nutrition by the method of foliar diagnosis. Pennsylvania Expt. Sta. Bul. 378. 1939.

TRELOAR, A. E. Elements of statistical reasoning. New York, John Wiley & Sons, Inc. 1939.

TYSDAL, H. M., and KIESSELBACH, T. A. Alfalfa nursery technic. Jour. Amer. Soc. Agron. 31:83–98. 1939.

VAIDYANATHAN, R. B. M. Discussion of sampling methods in developmental studies on cottons and the statistical treatment of results. Papers Conf. Scien. Res. Work Cotton, India, 1st: 424–436. 1937.

WEBSTER, C. C. A note on a uniformity trial with oil palms. Trop. Agr. (Trinidad) 16:15–19. 1939.
WEISS, M. G., and COX, G. M. Balanced incomplete block and lattice square designs for testing yield differences among large numbers of soybean varieties. Iowa Expt. Sta. Res. Bul. 257. 1939.
WIGGANS, R. G. The influence of space and arrangement on the production of soybean plants. Jour. Amer. Soc. Agron. 31:314–321. 1939.
YATES, F. The comparative advantages of systematic and randomized arrangements in the design of agricultural and biological experiments. Biometrika 30: 440–466. 1939.
————. The recovery of inter-block information in variety trials arranged in three-dimensional lattices. Ann. Eugen. Cambridge 9:136–156. 1939.
————. Orthogonal functions and tests of significance in the analysis of variance. Jour. Roy. Statis. Soc., Sup. 5:177–180. 1938.
YATES, F., and COCHRAN, W. G. The analysis of groups of experiments. Jour. Agr. Sci. 28:556–580. 1938.
YATES, F., and HALE, R. W. The analysis of Latin squares when two or more rows, columns, or treatments are missing. Jour. Roy. Statis. Soc., Sup. 6:67–79. 1939.
(Anon.) Crop estimation and its relation to agricultural meteorology. Jour. Roy. Statis. Soc., Sup. 5:1–45. 1938.
(Anon.) Sample plots in silvicultural research. U. S. Dept. Agr. Cir. 333. 1935.

F. R. IMMER
H. M. TYSDAL
H. M. STEECE, *Chairman*

SOIL TILTH

THE Joint Committee on Soil Tilth has been given the assignment of cooperating with a similar committee in the American Society of Agricultural Engineers to help determine or suggest a "measure of soil condition or tilth". The most difficult part of this assignment is to thoroughly understand what is meant by tilth. It is necessary to define tilth before methods for characterizing it can be designated. Due to the fact that most concepts of tilth do not agree in all respects, it will not be the purpose of this report to propose a definition of tilth to be used as a standard. An attempt will be made, however, to characterize the physical condition of the soil which is included in the concept of tilth.

Tilth is commonly defined as "the physical condition of the soil in its relation to plant growth". Let us visualize what this definition implies. In the first place, it is obvious that soil structure relationships constitute a large part of this physical condition; adequate aeration, sufficient moisture, ready infiltration of rainfall, etc. are characteristics of good tilth. But, does tilth only refer to structural relationships? When one thoroughly analyzes tilth he is immediately impressed with the fact that tilth also includes certain phases of soil consistency.

A soil in good tilth from the point of view of structure is generally described in terms of consistency. For example, such a soil is said to be mellow and friable; it handles easily. Friability is one of the major forms of soil consistency. It represents that stage in the soil-moisture curve where there is sufficient moisture around the particles to overcome the cohesive forces between the particle surfaces but not enough of a moisture film to cause plasticity. Therefore, it seems that we define tilth on the basis of certain structural properties of the soil that are manifested within a given range of soil consistency. In other words, we designate first the consistency range and then define the soil structure relationships that are involved in tilth within this range. For example, if one examines a silty clay loam soil when it is too wet or too dry, the impression of good tilth is rarely obtained. The soil does not handle well in either case and conditions are not favorable for good plant growth.

It is significant to point out that the range of friability in which tilth reaches an optimum from the standpoint of plant growth also is the same range in which the soil can be tilled with the least output of power and with the best effects upon granulation. In other words, even though tilth is defined primarily on the basis of plant growth effects, the physical conditions so characteristized in good tilth for plant growth are usually, not always, favorable to good tillage. In many instances, tillage is responsible for the achievement of good tilth.

Therefore, irrespective of how we define tilth, let us keep in mind that it refers to certain structural conditions of the soil within a given range of consistency.

Various methods have been proposed to measure soil tilth. Keen and his associates in England have attempted to use the size-distribution of various clods as a measure of tilth. Soils were screened dry in the field. This technique has been modified recently along the lines of the Russian investigators, who wet-sieve the soil in benzene. The English workers attach considerable importance to the amount of material finer than ⅝ inches in diameter.

Several Russian investigators have emphasized the importance of granulation and porosity as measures of tilth. Most of their results indicate that a seedbed constituted of aggregates from 2 to 3 mm. in diameter is the best for plant growth. The soil pore space should be about equally divided between capillary and non-capillary pores. When the non-capillary porosity is lower than 10% by volume of the total soil, there is poor tilth. Von Nitzsch of Germany also employs pore space as a criterion of good tilth

Yoder of Alabama and Baver of Ohio have obtained a considerable amount of data to show that the non-capillary porosity of the soil is a reliable index of tilth in relation to plant growth. The former has shown that cotton yields on artificially prepared seedbeds are definitely associated with non-capillary porosity of these seedbeds. The latter has observed that the production of greenhouse soils and sugar beet soils are closely related to the non-capillary porosity. Of course, non-capillary porosity is related to granulation in most cases.

Henin of France has used a penetrometer to obtain an index of tilth. This instrument measures the force of penetration of a metal point into the soil as a function of depth. The force required for penetration is considered an index of tilth. Schofield and his co-workers in England have proposed that compressibility be used to measure tilth. The more that a soil can be compressed, the better the tilth; the amount of compression in this case denotes the extent of looseness.

The methods of Henin and Schofield measure both consistency and structural effects. Penetration and compressibility are primarily dependent upon soil consistency but vary with structure. In other words, for a given soil structure, penetration and compressibility will vary with consistency. Therefore, although these types of determinations offer considerable possibilities for obtaining an over-all measure of tilth, they have not been characterized adequately enough as yet in terms of other soil properties.

Methods based upon granulation and porosity seem to this Committee to offer the most promising means at the present for characterizing soil tilth. Determinations of porosity must include not only the total porosity but also the relative distribution of the large and small pores. Cores of soils in their natural structure should always be used. The ideal technique would be to obtain a complete pF curve (size-distribution of pores) on each core sample. This requires considerable time. In case the obtaining of a complete curve is not possible, sufficiently reliable results can be had by determining the non-capillary porosity as the difference in the air capacity at zero tension and at a pF of 1.5 to 2.0. A clod or aggregate

analysis of the seedbed will undoubtedly give valuable supplementary data to help interpret the porosity results. Such an analysis may be made either by dry sieving, sieving in benzene, or sieving in water. The stability of a given tilth condition can probably be estimated from the differences between sieving in water and in benzene.

Therefore, this Committee recommends that the following measurements serve as an index of tilth, with the most desirable first:

1. Determination of total capillary and non-capillary porosity on undisturbed core samples of the soil.

2. Aggregate and clod analysis of the soil.

3. From a purely research point of view to obtain any information on penetration or compressibility that it might be feasible to procure.

J. F. LUTZ R. J. MUCKENHIRN
H. E. MIDDLETON L. D. BAVER, *Chairman*

VARIETAL STANDARDIZATION AND REGISTRATION

DURING the year, the Committee registered four varieties of wheat, five varieties of oats, one variety of barley, and one of cotton, as follows:

WHEAT

Wabash, Reg. No. 324, developed cooperatively by the Purdue University Agricultural Experiment Station and the U S. Department of Agriculture.

Renown, Reg. No. 325, Coronation, Reg. No. 326, and Regent, Reg. No. 327, developed by the Dominion Rust Research Laboratory, Cereal Division, Winnipeg, Manitoba, Canada, of the Dominion Experimental Farms System.

OATS

Boone, Reg. No. 87, Hancock, Reg. No. 88, and Marion, Reg. No. 89, developed in cooperative experiments by the Iowa Agricultural Experiment Station and the U. S. Department of Agriculture.

Fulwin, Reg. No. 90, and Tennex, Reg. No. 91, developed by the Tennessee Agricultural Experiment Station.

BARLEY

Rex, Reg. No. 8, developed by the University of Saskatchewan, Saskatoon, Sask., Canada.

COTTON

Texacala, Reg. No. 35, developed by John D. Rogers, Navosota, Texas.

Descriptions of these varieties, and the yields and other records that form the basis for registration, are being prepared for publication in the JOURNAL.

Requests have been received for the registration of improved varieties of flax, sweet clover, and alfalfa. These requests were received at too late a date to circularize all members of the committee. In order to expedite the registration of these three crops, the committee requests authorization by the Society to approve their registration when, after canvassing the entire committee membership, such registration is deemed desirable. The committee also desires authorization by the Society at this time for preparing necessary rules and regulations, and specific requirements, for registering flax, sweet clover, and alfalfa, and also requests that

the President of the Society be authorized to appoint members of the Committee on Varietal Standardization and Registration who shall serve as specialists for handling the registration of the three crops.

H. B. Brown, H. K. Hayes, T. R. Stanton
J. Allen Clark, R. E. Karper, G. H. Stringfield
E. F. Gaines, W. J. Morse, M. A. McCall, *Chairman*

EXTENSION PROGRAM

WE ARE pleased to report the largest attendance of extension agronomists at any meeting in the history of the Society. The large attendance of extension agronomists made possible several valuable regional and subject matter conferences as follows: (a) Conference on production of winter legume seed including problems inherent in AAA grants of aid; (b) conference on seed certification in the South; and (C) conference on policies concerning distribution of new alfalfa varieties. There may be similar problems which will make highly desirable attendance of extension agronomists at future meetings.

We recommend (a) that the name of the committee on Extension Program be changed to read, Committee on Extension Participation; and (b) that the Chairman of the Committee be a member of program committees.

J. S. Owens, Earl Jones
O. S. Fisher, J. C. Lowery, *Chairman*

STUDENT SECTIONS

THE addition of the University of Tennessee to membership in the Student Section of the American Society of Agronomy makes a total of 19 institutions having chapters.

The national officers of the Student Section issued a news-letter early this fall. A meeting is planned at the time of the International Grain and Hay Show in Chicago.

Some 85 essays were entered in the Society's essay contest. The topic for this year's contest was, "The Work of Early American Agronomists". The authors of the 10 best papers were: 1, Melvin H. Kreifels, University of Nebraska; 2, George R. Page, University of Minnesota; 3, Emil O. Haudrich, University of Illinois; 4, Loren E. Juhl, University of Illinois; 5, Lawrence Treakle, University of Nebraska; 6, Carl A. Rovey, University of Arizona; 7, C. Rudolph Gustafson, University of Minnesota; 8, Benjamin Westrate, Michigan State College; 9, Ernest J. Guilloud, Jr., Texas A. & M. College; and 10, Harold Johansen, University of Minnesota.

It is recommended that the abstracts of the three best papers be printed in the Journal as a part of this report.

The committee proposes that the Society continue to sponsor the essay contest for another year and urges that members of the Society stimulate more students to participate in this activity.

G. H. Dungan, J. W. Zahnley
A. L. Frolik, H. K. Wilson, *Chairman*
J. B. Peterson

THE WORK OF AN EARLY AMERICAN AGRONOMIST

By Melvin H. Kreifels, University of Nebraska

Dr. Thomas Lyttleton Lyon probably did more outstanding work in the field of agronomy than did any other man of his time. Most of his work was done in soils with emphasis on soil nitrates. His outstanding contribution to nitrogen research has been to develop a fuller and more fundamental knowledge of the natural factors which control the supply of nitrates in the soil. His investigations include the influence of cropping system on nitrate formation, the influence of soil moisture and tillage operations on nitrate production, factors which contribute to the loss of nitrates by leaching, influence of green manures on supply of nitrates and of total nitrogen in the soil, and the effect of mechanical conditions of the soil on the availability of sodium nitrate.

From his work Lyon was able to draw conclusions which have been used to this day. The plant has a definite effect upon the soil solution. The relative quantities of certain anions and cations in solution influence the rate of the nitrifying process. Organic matter affects bacterial activity which brings about the transformation of energy. Alfalfa soil produces nitrates more rapidly than does timothy soil because of the direct effects of the plant on nitrate production, however there is little difference in the total amount of nitrogen present in the two soils. The green plants and the organisms in the soil compete for the nitrogen present. Part, or possibly all of the nitrogen which is utilized by the organisms is not lost but remains in the soil.

The amount of lime in the soil does not affect the loss of nitrates by leaching, but it does affect the loss of magnesium. Under normal conditions the total quantity of bases is less in drainage water of limed soil, however the presence of potassium sulfate increases the loss of calcium by leaching.

At Nebraska Lyon worked on wheat and meadow and forage crops. In breeding of wheats he found that the gliadin and glutenin content of wheats could be increased along with an increase in yield. By selecting over a period of years, yields of wheat high in nitrogen could be raised to the level of that which the heavy large kernels produced. Generally the production of nitrogen in wheat per acre is greater in dry years. Lyon found brome grass to be best adapted to Nebraska conditions with the exceptions of meadow fescue and orchard grass. Alfalfa is the best forage plant, its value lying chiefly in the production of hay.

While at Nebraska Lyon was instrumental in obtaining cooperative experiments between the U. S. Dept. of Agriculture and the several stations scattered throughout the United States. He published several books. His grain grading texts and his soil books are used in almost every agricultural college.

THE WORK OF AN EARLY AMERICAN AGRONOMIST

By George R. Page, University of Minnesota

Willet Martin Hays was born October 19, 1859 on a farm in Hardin County, Iowa. When he was 12 years of age, his father died, and he and an older brother became the active operators of the farm supervised by their mother. This was his frontier.

While a student at Iowa State College, he was given part-time employment on field crops experiments, thus gaining his first insight into scientific methods. Upon graduation from Iowa State College in 1885, he served for a year as an assistant to Mr. S. A. Knapp, then agriculturist at the Iowa State College and Experiment Station. It was at this period that agitation for experiment station work was at its

height. As a consequence, Hays found himself in an atmosphere saturated with the idea of science in its application to agriculture, and he became thoroughly inbred with a desire to promote this type of research and education.

The research frontier was opened to Hays by the passage of the Hatch Act in 1887, which marked the advent of federally endowed experiment station work. The organization of state experiment stations proceeded rapidly and created a demand for men trained in science and in agriculture. Hays was drafted when the Minnesota School of Agriculture was organized in 1888. He was appointed to an instructorship in agriculture in the school and served as assistant agriculturist in the Experiment Station under Director E. D. Porter.

Here he found two frontiers which strongly stimulated his imagination and ambition. His training and experience were such as to fit him for just such a situation. With characteristic foresight and vigor he began the attack. His first experiments were a study of the root habits of corn and other plants, which led to a new understanding of the principles involved in tillage. His contributions to these subjects proved stimulating to workers in other stations and led to definite improvement in tillage operations and in the methods of crop production.

Hays conceived the idea that "there are Shakspears among plants". Recognizing the individual plant as a unit of improvement and being cognizant of the effects of hybridization, he set about finding ways to breed plants so that he might "find the Shakspears".

Introductions of varieties and samples of wheat were made and approximately 200 studied as early as 1889. Field and laboratory methods were developed for planting, harvesting, and studying the progeny of selections and a standardized program of breeding methods with small grains was formulated. The importance of quality was recognized and milling and baking studies were essential part of the early wheat-breeding program.

The importance of selection was clearly recognized. The methods adopted for self-pollinated plants consisted of an initial selection of promising individuals in field plots and their progeny study in centgener plots, e.g. 100 plants. Among commercially important early production of Minnesota plant breeders were two varieties of wheat, Improved Fife (Minn. 163) and Haynes Bluestem (Minn. 169) and Minn. No. 13 Corn. Of equal or greater potential value was the emphasis on the scientific importance of attacking problems in plant breeding on the basis of learning the fundamental principles involved.

Recognizing the influence of environment in affecting changes in plants and in bringing out new adaptation, Hays advocated the establishment of branch stations. The five branch agricultural experiment stations of Minnesota stand as a monument to his wisdom and foresight.

THE WORK OF EARLY AMERICAN AGRONOMISTS

By Emil Haudrich, University of Illinois

AGRICULTURE always was, and still is, the most important field of science. Our knowledge of this field at present is still rather limited, although for years men have spent their entire lives uncovering facts relating to the science of agriculture.

Cyril George Hopkins was one of these men. He was born upon a farm near Chatfield, Minnesota, in 1886. In 1894 he came to the Agricultural Experiment Station of the University of Illinois. He was a hard and conscientious worker and soon became a prominent man there.

He first worked on plant improvement but soon shifted his interests to soils where he did his most outstanding work. He won renown for advocating the Illinois system of permanent agriculture which recognizes plant food as the limiting factor in crop production. In furtherance of his teachings Doctor Hopkins established experimental fields in various parts of the state and was also instrumental in making the first soil survey in Illinois.

The outstanding characteristic of Doctor Hopkins was that he took special pains to make his findings and his teachings practical and understandable, so that every farmer could put them into practice and benefit directly therefrom. When we think of the things that he has done, and what the farmers who practiced his teachings have done, we can see the real significance of his work. By his thorough and accurate scientific research, his practical application of his findings, and by the self-sacrificing way in which he preached the gospel of soil fertility, he won the respect and confidence of scientists and farmers alike.

Doctor Edward Murray East was another early American agronomist who did much for agriculture. His chief interest was plant breeding, on which he was an authority. He was born at DuQuoin, Illinois, in 1879. He started his career at the University of Illinois, but did his most outstanding work at the Connecticut Experiment Station, and also at Harvard University.

Doctor East did some research work on the improvement of such crops as potatoes and tobacco, but his chief interest was corn. He was one of the first breeders who did extensive research to determine the application of Mendel's Laws of Heredity to our farm crops.

He began experiments in 1905 to determine the results of inbreeding and hybridizing corn. When we realize that as early as 1909, a method for the commercial utilization of hybrid corn was outlined that differs only in minor details from that now in use, we can appreciate the work of Doctor East in this field of genetics.

When we consider that he developed a scientific method of corn breeding, and contributed greatly to the establishment of the laws underlying the inheritance of measurable characters, we can readily see why he is considered among the great scientists of America.

Through the pioneering work of our early American agronomists the cornerstone of scientific agriculture has been laid. Now it is the task of present and future agronomists to build on this foundation.

FERTILIZERS

Subcommittee on Soil Testing.—During the year the Subcommittee on Soil Testing, with the help of the Division of Soil Chemistry of the U. S. Bureau of Plant Industry, assembled a collection of 31 standard soil samples of widely varying genetic and geographic origin. Sub-sample collections were submitted to workers in several states for correlative testing, the understanding being that workers were to employ any desired methods and report their results to the chairman of the Subcommittee. Preliminary study of 15 sets of data so far submitted shows a fair degree of consistency between the results of different workers and between different methods. There are, however, rather clear indications that the same technics cannot be employed saitsfactorily with all soils, also that standards of interpretation vary considerably among individual workers. It is planned to continue this work and it is hoped that when the results of chemical studies now being made on these soils by the Division of Soil Chemistry are available, the

reasons for variations and apparent discrepancies among methods may be elucidated. Sets of check soils for correlation of "quick test" methods are still available for distribution on request through Dr. H. G. Byers, Division of Soil Chemistry, Bureau of Plant Industry, Washington, D. C.

M. F. MORGAN, *Chairman*

Subcommittee on Fertilizer Grades.—Through the cooperation of a group of fertilizer manufacturers operating well over 100 factories and supplying approximately 45% to 50% of the fertilizer used in this country, exclusive of the Pacific Coast, confidential data were obtained concerning the cost of manufacturing and marketing a large number of fertilizer analyses. These data reveal that as the number of fertilizer grades is increased there is a marked increase in cost of production due to loss of time in making changes from one analysis to another. This loss may amount to from one-fourth to one-half the possible output of a plant depending on the number of changes made and contributing factors. Increased capital investment for storage, loss of power, cost of registration, loss of time in printing bags, and increased cost of chemical control make further substantial additions to the cost of supplying a large number of analyses. The Committee is indebted to Mr. D. D. Long for collecting and summarizing the data.

A committee in the northeastern states under the leadership of Professor M. F. Morgan has held several conferences of representatives of the industry, agronomists, and members of the Soil Improvement Committee of District 1. It was agreed to work toward (1) a minimum of 20 units in accepted grades, (2) a minimum of 8% nitrogen or potash or the two combined in accepted grades, (3) publicity and endorsement of agronomists' recommended ratios for specific crops. A list of 12 ratios was agreed upon as generally suitable for New England conditions and acceptable grades were approved for the 1940 season. Three ratios were accepted as meeting the special needs of tobacco in New England.

Middle Atlantic states have also come to an agreement concerning a list of ratios and grades to be recommended in the various states.

A comparison of the analysis and number of grades recommended by agronomists and offered for sale in the various states has been made. The number of grades recommended in a state varies from 10 to 30. The number of grades offered for sale in a state runs from 10 to 109 In one state, 14 of the recommended grades were not offered for sale and the number of unrecommended grades offered for sale varied from 16 to 91. The number of grades recommended in both of two adjoining states varied from 3 to 19. The number of grades offered for sale in only one of two adjoining states ranged from 11 to 114.

There is evidently much opportunity for agronomists to cooperate with each other and with the industry in unifying recommendations and for representatives of the industry to restrict offerings.

C. E. MILLAR, *Chairman*

Subcommittee on Symptoms of Malnutrition in Plants.—The members of the Subcommittee have spent the year collecting and preparing suitable material for the proposed book on "Deficiency Symptoms". Mr. Gove Hambidge of the U. S. Dept. of Agriculture has been selected to edit the material and has already gone over the subject matter for the tobacco chapter. A conference was held with a possible publisher who reacted favorably in regard to handling the publication. It is hoped that other publishers can be approached when the chapter authors submit additional copy. The financial sponsorship of the book is now finally assured.

At a meeting of the Subcommittee in Washington on October 13 good progress on preparation of material was reported by all chapter authors and it was the opinion of most authors that they could have their material ready by January 1, 1940.

J. E. McMURTREY, *Chairman*

Subcommittee on Fertilizer Reaction.—The Subcommittee has continued to sponsor investigations on the factors influencing the availability of different sources of magnesium in complete fertilizers. This work was completed during the year and was reported to the Association of Official Agricultural Chemists at a recent meeting in Washington. The data are being utilized by that organization in evaluating different analytical methods for available magnesia in complete fertilizers. The Subcommittee continues to sponsor field experiments on several problems relating to the use of acid vs. non-acid forming fertilizers. In this they have received fine cooperation from several state experiment stations and the Division of Soil Fertility of the Bureau of Plant Industry.

F. W. PARKER, *Chairman*

Subcommittee on Methods of Fertilizer Application.—The Subcommittee has continued to participate in the work of the National Joint Committee on Fertilizer Application. The extensive program on machine placement of fertilizers has been continued and last year included 157 experiments at 70 locations in 26 states and involved 30 different crops. Increased attention is being given to fertilizer placement on organic soils and on irrigated land. Studies dealing with localized applications of fertilizer simultaneously at two depths instead of the customary single depth give promise of better efficiency under varying moisture conditions. Promising results have also been obtained in experiments in which the three fertilizing elements have been placed differentially with respect to the seed or plant, also in experiments in which nitrogen fertilizers have been incorporated by plowing under with crop residues. Increased attention is being given to certain of the more fundamental conditions affecting fertilizer application and it is expected that these studies will permit greater refinement in methods to meet variations in climate and soil.

ROBT. M. SALTER, *Chairman*

PASTURE IMPROVEMENT

THE JOINT COMMITTEE on PASTURE IMPROVEMENT during the past year has been concerned primarily with the inter-Society organization and the development of a procedure for going forward with the joint work on the comparative nutritive value and relative cost of forage and other crops. Your previous Chairman, P. V. Cardon, succeeded in bringing about the organization of an inter-Society Committee with representatives from the American Society of Animal Production, American Dairy Science Association, Canadian Committee on Pasture and Hay, and the American Society of Agronomy. Each Society has given, or will give, consideration to the joint problem at its summer or fall meetings.

A "Grassland Conference" was held in conjunction with the joint summer meetings of the Northeastern and Corn Belt Sections of the Society at Wooster, Ohio. In addition to a number of other topics of interest to specialists concerned with grassland management and improvement, there was a discussion of "methods for evaluating pastures in relation to each other and to other harvested feed crops".

A report on the conference was prepared, mimeographed and distributed to those in attendance at the meeting, and others interested in pasture improvement. A resolution was passed to the effect "that future conferences be held, and that reports of the discussions be forwarded to Experiment Station Directors and all other interested individuals". The following extract from the report of the "Grassland Conference" indicates the nature of the discussion on the comparative nutritive value of forage and other crops:

"Pasture improvement based on findings of Experiment Station workers and others has not found as wide a reception among farmers as the condition of millions of acres of pasture land would appear to warrant. This is believed to be due in large part to the scarcity of information relative to (1) the value of pasture crops in relation to each other and (2) the value of pasture crops in relation to other harvested feed crops when grown under similar soil and cultural conditions. At present 13 widely different methods are used in evaluating pastures and improved pasture practices. There is need for a standardization of methodology. Any method of evaluation should be based on livestock and livestock products produced and must consider maintenance, production, gains or losses in live weight and supplementary feed required.

"It was suggested that the feeding value of different pasture crops be determined by (1) grazing on comparatively small replicated areas under field conditions, (2) feeding the harvested green forage under standardized controlled conditions, (3) feeding the harvested forage as hay and (4) feed the harvested forage as silage."

Another grassland meeting was held at the Great Basin Branch Station of the Intermountain Forest and Range Experiment Station, Ephraim, Utah. A report on the meeting was made by the U. S. Forest Service, under the title "Proceedings of the Range Research Seminar, July 10–22, 1939". Special consideration was given to nutritional problems. The following extract indicates the nature of the discussion:

"The necessity for detailed information on nutritional problems of range livestock is becoming more and more evident as range management progresses. The utilization standards studies in particular have shown the need for more definite information on nutritional values of range forage plants through the season and in relation to different degrees of use. Animal nutrition studies have been the subject of experimentation for a great many years by State Agricultural Experiment Stations.

"Most of the effort of these institutions, however, has been expanded on animal nutrition studies under feed lot rather than range conditions. Before the Agricultural Experiment Stations can expand their program of research to include nutritional studies of range plants and animals, additional funds, equipment and personnel will be needed. The degree of participation by the Forest Service should depend largely on the adequacy of coverage within the field of endeavor; that is, if the state institutions satisfactorily provide the needed information on nutritional phases, participation then should be restricted to cooperative assistance.

"The tentative program of western-wide determination of chemical analyses of range plants prepared in 1938 by the Bureau of Animal Industry and the Forest Service represents a beginning in the interpretation of range nutritional problems. As a basis for preparation of further programs of this nature your committee desires to list some of the specific nutritional problems of range livestock and range plants that need investigation: (1) Forage requirements of the grazing animal; (2) Nutritional values of range forage plants in relation to degree, season, kind of

use, past treatment, and soils; (3) Relation of nutritional values of various vegetation types to forage acre requirements and to the growth, maintenance and production of grazing animals; (4) How to handle areas of seasonably palatable forage on a year-long basis; (5) Effects of different methods of handling on the nutrition of range animals; (6) Effect of elapsed time, including weathering, on nutritional values of range forage plants, and (7) Nutritional values of the principal range forage species by actual feeding tests."

It is evident from the several conferences held to date that the desired progress on this important topic cannot be made satisfactorily until the necessary assistance is made available to (1) compile available information as an aid in the formulation of experimental work for distribution to investigators interested and in a position to give consideration to studies of relative values of pasture, forage, and other crops; and (2) the development of a carefully conceived investigational procedure for consideration by agronomists and animal specialists interested in pasture research. Funds are being sought for this purpose.

JOHN ABBOTT	R. D. LEWIS
B. A. BROWN	O. MCCONKEY
P. V. CARDON	GEORGE STEWART
D. R. DODD	PAUL TABOR
C. R. ENLOW	O. S. AAMODT, *Chairman*

RESOLUTIONS

IT BECOMES the duty of the Committee on Resolutions to announce the deaths of the following members of the American Society of Agronomy during the past year: Dr. J. G. Lipman of New Jersey; Dr. C. F. Shaw of California; Dr. F. W. Tinney of the Bureau of Plant Industry located at Madison, Wisconsin; Dr. A. A. Bryan of the Bureau of Plant Industry located at Ames, Iowa; Professor J. G. Hutton of South Dakota; and Professor F. T. Musbach of Wisconsin.

On behalf of the American Society of Agronomy the Committee makes this announcement with regret and a feeling of real loss. Detailed accounts of these men are attached to this report and will be published in the JOURNAL. Shall we stand in a moment of silence in honor of these agronomists.

M. F. MILLER	J. D. LUCKETT, *ex-officio*
R. I. THROCKMORTON	F. D. KEIM, *Chairman*
O. S. AAMODT	

ARTHUR ALFRED BRYAN

ARTHUR ALFRED BRYAN, Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, died at his home, 712 Ridgewood Avenue, Ames, Iowa, on the morning of February 22, 1939. He had been in poor health for two or three years and his illness had confined him to his home for several weeks.

Doctor Bryan was born at Princeton, Missouri, on December 2, 1890. He entered the College of Agriculture of the University of Missouri in 1912 and graduated with the degree of B.S. in Agriculture in 1915. He was granted the Master's degree by the Iowa State College in 1925 and the Ph.D. degree by the same institution in 1931. From February 1916 to December 1917 he was Scientific Assistant in the Office of Corn Investigations of the Bureau of Plant Industry. In December 1917 he was transferred to the Office of Western Irrigation Agricul-

ture and was Acting Superintendent of the San Antonio Experiment Station, San Antonio, Texas, until February 1920, when he resigned his position and engaged in farming in southwestern Texas. In July 1922 he was appointed Junior Agronomist in the Office of Cereal Investigations and assigned to the Iowa Agricultural Experiment Station in charge of the agronomic phases of the cooperative Iowa Corn Yield Test carried on by the Iowa Corn and Small Grain Growers' Association, the Farm Crops Section of the Iowa Agricultural Experiment Station, and the Office of Cereal Investigations. He remained in this work until January 1934 when he was placed in charge of the cooperative Iowa Corn Improvement Program. From that time until his death his efforts were concentrated on the breeding phases of corn improvement.

In the passing of Doctor Bryan we who were closely associated with him have lost a friend whose integrity, sincerity, and kindliness were unfailing. We have not known a man who set higher moral standards for himself and attained them in so quiet and unassuming a manner. He gave unsparingly of himself to all those associated with him as well as to religious and civic organizations.

Doctor Bryan was an extremely diligent and painstaking worker. The high scientific esteem in which the Iowa Corn Yield Test is held is largely the result of his efforts. Through his interest in statistical methods and improved plot technics he has maintained a standard of perfection in the Yield Test that has made it an outstanding example for experiments of this kind.

Doctor Bryan is survived by his widow, the former Miss Jessie Miller of Newton, Missouri, and by his daughter Phyllis, a junior in Home Economics, at Iowa State College. He also leaves two brothers, Reece Bryan, of Princeton, Missouri, and Roy Bryan, of Mercer, Missouri, and a sister, Mrs. Ike Hoover, of Princeton, Missouri.—MERLE T. JENKINS.

JOSEPH GLADDEN HUTTON

THE American Society of Agronomy lost a valuable member in the death of Professor Joseph Gladden Hutton, in Brookings, South Dakota, September 23, 1939.

Mr. Hutton was born near Montecelo, Indiana, November 3, 1873. He was the son of William H. and Mary J. (Gladden) Hutton. He was reared on a farm and attended a one-room district school. He later attended the Indiana State Normal University at Terre Haute, from which institution he graduated. As a student there he came under the tutilage of Dr. Dryer. He was also assistant in biology, 1898–1900. He was principal of high school and later superintendent of schools, Beardstown, Illinois, 1901–08; received his B.S. degree from the University of Chicago, 1908; and his M.S. from the University of Illinois, 1910. He served as assistant in geology, University of Illinois, 1908–11. June 15, 1904 he was married to Emilie (Feddersen) Hutton; children, Helma Louise (Mrs. H. L. Keil), Mary Erne-Jean (Mrs. Moras Schubert), and Joseph Gladden Jr.

Professor Hutton came to South Dakota State College and Experiment Station in June, 1911, and served this institution continuously as Associate Agronomist in charge of Soils Instruction and Research until the time of his death. He was granted leave from March 5, 1935, to October 1, 1936, to cooperate with the U. S. Soil Conservation Service.

Whatever Mr. Hutton did throughout his career was accurately and thoroughly carried out. The following paragraph received from the Registrar of his Alma Mater in reply to an inquiry for the usual information about his undergraduate

career seems characteristic: ". . . admitted to the University of Chicago on July 3, 1899 . . . His major field was botany. He maintained a scholastic average slightly below A which was unusually excellent. He received honorable mention for excellence in his senior college work and also received honors in botany. Mr. Hutton was elected to Phi Beta Kappa."

He matriculated as a graduate student in the University of Illinois, 1908, and received his degree of M.S. (Geology) in 1910. He had studied Geology with Professor T. E. Savage and Professor S. W. Cushing. In the latter part of his sojourn as a graduate student in Illinois, he studied soils with the late C. G. Hopkins. It is pertinent to say that the academic training which had been secured by Mr. Hutton previous to his study of soils consisting of thorough disciplines in biology and later geology, made it possible for him to become a competent soil scientist. If it is possible to speak relatively of such a matter, he would surely be regarded by his colleagues as one of the most competent men in the country—or in the world.

It was his definite proposition when he came to South Dakota in 1911 to contribute to knowledge in soils with especial reference to correlation between geologic formation and soil type. It was his belief that such correlation is not only fundamental, but that it had not been too clearly emphasized in previous years. Always appreciative of the work of others, his belief in the matter just indicated and his previous training gave direction to his later teaching and investigational work. He learned the relation between soils and farm management from C. G. Hopkins, and what he learned he never forgot. The following statement relative to Mr. Hutton's connection with the American Society of Agronomy was contributed in the following reply from Dean M. F. Miller:

"I find that his large contribution was in connection with the Soil Survey Association. He was Vice-president of this Association in 1928–29 and President in 1929–30. He served on a number of committees, the most important of which were as follows:

"Chairman of the Committee on Soil Color Standards, 1920–1932. He did much original work in connection with his assignment, making a real contribution to the methods of evaluating soil colors to be used in connection with soil classification. He presented reports at the annual meetings regularly during this 12-year period.

"Chairman of the Committee on Land Use, 1932–33. This was in the early days of the interest in land-use activities, and a committee was set up in the Soil Survey Association for this purpose. However, this was discontinued in 1933 under this title and was set up as a committee on Soil Conservation.

"Chairman of the Committee on Soil Conservation, 1933–36. He presented regular reports in connection with this important subject during these eventful years. However, in 1936, the Soil Survey Association was merged with the Soils Section of the American Society of Agronomy, and these various committees were discontinued.

"Professor Hutton was widely known among soil scientists for his work in connection with soil classification and soil survey. He was a regular attendant at the annual meetings and each year appeared on the program. He had a host of friends."

The foregoing activities in connection with scientific soils organizations—state, national, and international—may be regarded as important, and withall as as effective as any other work he did. He labored diligently at it, much of the time intensely. During his period of work in South Dakota the state legislature financed

a state soil survey through the years 1917–27, during which time Mr. Hutton was in direct charge of soil survey and soil research for the state. Nine counties were surveyed in cooperation with the then U. S. Bureau of Soils. The late Dr. C. F. Marbut was director of the Soil Survey and W. I. Watkins, cooperator here in the field. The late Thomas D. Rice was inspector. More recently a soil area map (unpublished) was composed as a result of a survey of South Dakota by Joseph Gladden Hutton and W. I. Watkins. The foregoing soil surveys directed or participated in by Mr. Hutton have contributed mainly to knowledge of soil types and areas in South Dakota. Recently Mr. Hutton published "Thirty Years of Soil Fertility in South Dakota" (South Dakota Agr. Exp. Sta. Bul. 325). This bulletin is intended to be a summary of crop yields resulting from differential treatments under conditions of environment in this area. People who know about the details of carrying through soil and crop experiments over long periods with or without plenty of advice from democracy will be able to appreciate such a contribution. Mr. Hutton was author or co-author of a number of bulletins and circulars, likewise of various papers in scientific journals.

He was a member of American Society for Advancement of Science, the American Society of Agronomy, American Genetic Association, National Geographic Society, State academies of South Dakota, Indiana, and Illinois, International Society of Soil Science, Alpha Zeta, and Sigma Chi. He served during the World War with the rank of Second Lieutenant.—A. N. HUME.

JACOB GOODALE LIPMAN

WITH the passing of Doctor Lipman, American agriculture has lost a brilliant investigator and an outstanding contributor to our knowledge of the soil and its relation to plant growth and agricultural practice.

A graduate of Rutgers College of the Class of 1898, a member of the staff of the New Jersey Agricultural Experiment Station since 1899, with only a brief interruption for graduate work, Director of the Experiment Station since 1911 and Dean of the College since 1914, Dr. Lipman has played a most important role in the building of these institutions from a small foundation to one occupying a leading place among the teaching and research institutions in this country. His keen scientific mind, his practical approach to the many difficult problems that he had to face, his outstanding administrative ability, and especially his profound humanitarianism in his relation to his colleagues and his subordinates, were well recognized. Following closely in the footsteps of his two distinguished predecessors, Dr. George H. Cook and Dr. E. B. Voorhees, Dr. Lipman continued their pioneer work in the field of agricultural science and signally succeeded in bringing together science and practice for the common good.

In his own selected field of work, namely in soil science, Doctor Lipman has occupied an outstanding place. His own contributions to our knowledge of the problems of nitrogen-fixation, decomposition of organic matter, and denitrification have attracted world-wide attention. Doctor Lipman's writings, including his book "Bacteria in Relation to Country Life"; the journal of SOIL SCIENCE, which he established and edited for a period of 24 years; his editorship of various monographs in agricultural science; his contributions to numerous farm journals and agricultural encyclopedias—all stand out among his great achievements.

Outstanding among the contributions of Doctor Lipman was his leadership in the scientific societies of this country and of the world at large. As former President of the Association of Land Grant Colleges and Universities, as President of

the American Society of Agronomy of which he was a charter member, and as first President of the International Society of Soil Science, he has helped to crystallize the progress made in agricultural science. This was acknowledged by numerous national and international societies, as evidenced by the many honors showered upon him by governments, universities and scientific societies, by medals and memberships of editorial boards of foreign and domestic journals, etc. He served as American delegate to the International Institute of Agriculture at Rome in 1922, 1924, and 1926, to the International Conference of Soil Science in Prague in 1922 and in Rome in 1924, as President of the First International Congress of Soil Science at Washington in 1927 and as chairman of the American delegation to the Third International Congress of Soil Science in 1935 at Oxford, England. In 1929 he was designated to serve as one of the representatives of the state experiment stations on a national committee on soil erosion to formulate plans for a national approach to this important problem. He served on numerous committees of a national or of a state nature.

The recognition of the importance of microbiological processes in soil fertility and in plant nutrition was well expressed by Dr. Lipman in one of his chapters on the "Microbiology of the Soil" published, in 1911, in Marshall's Microbiology. "Soil-formation is not entirely a mechanical or chemical process. Even before the layer of weathered rock acquires any appreciable depth, microscopical and macroscopical forms of life gain a foothold on the uneven surface. With the aid of sunlight they build organic compounds and make use of the combined or elementary nitrogen of the atmosphere. Their life activities result in the production of carbon dioxide and of varying organic and inorganic acids which in their turn react with the constituents of the rock particles. In this manner the biological activities become of utmost moment in the transformation and migration of mineral substances in nature. Soil science must build a foundation large enough and strong enough to support the study of plant food resources and their mobilization, of the inter-relations of soil and plants and of soil characteristics and peculiarities as reflected in the make-up of plants, animals and man. As students of soils and soil resources we must think not only of plant-food but of its mobilization. We must consider the soil solution not alone in its local relations, but as a part of a great mass of fresh water moving to the sea. We must consider the cubic miles of sediment deposited at the outlets of great rivers as a toll upon the land and as a tax on those who till it. We must include in our reckoning the circulation of carbon, hydrogen, nitrogen and sulfur as affected by combustion, decay and fermentation. We must think, finally, of ancient plant and animals, as well as of those now living, as possessors of something that in the workshop of creation must be used over and over again. We are the technical advisers to the nations who are trustees of precious raw materials. These must be used wisely and conserved effectively in order that human kind may travel with the least pain and sorrow on its road of destiny."

The contributions of Doctor Lipman to soil science were well expressed by Sir John Russell, in an article published in the fortieth volume of Soil Science dedicated to its editor: "He began his work at a critical period in the history of agriculture. The new science of bacteriology, just being applied to agriculture, had revealed a new and hitherto completely unexpected world of life-living organisms so small and yet so numerous that the mind utterly failed to grasp the figures expressing either their size or their number. In the agricultural laboratories the achievements of Winogradsky, Beijerinck, Warington, and others had shown a wonderful picture of soil life, rousing the imagination and stimulating the scien-

tific interest of many of the younger workers of the day. They had used culture methods, in the main the elective methods, excluding all organisms but the one under investigation and they had achieved marvelous results. Doctor Lipman began also by using these methods to study a question which was then causing considerable commotion in agricultural circles, the loss of nitrogen from farmyard manure. This had always been regarded by practical men as the ideal fertilizer, and the battle of the giants of those days raged about the question; farmyard manure versus artificials. His discovery that Azotobacter by itself can fix nitrogen is of historic importance, but equally valuable was his gradual recognition of the importance of the compositions of organic matter—its carbon-nitrogen ratio—on its decomposition in the soil."

The loss of Doctor Lipman's leadership, his scientific acumen, and his humanitarian qualities are profoundly felt, not only by those who were in close daily contact with him, but also by his innumerable friends and his former associates and students scattered throughout this and many foreign countries. To few men is it given to exert such a profound influence on so many fields of scientific endeavor, and to become an inspiration and help to so many of his fellow men.—SELMAN A. WAKSMAN.

FREDERICK LUDWIG MUSBACH

FREDERICK LUDWIG MUSBACH, Professor of Soils in the Wisconsin College of Agriculture, was killed in an automobile accident September 14, 1939. He was born on a Wisconsin farm March 10, 1877. After completing his course in the Milwaukee Normal School he taught a few years before coming to the University and was graduated from the College of Agriculture in 1909. He was at once appointed assistant in the college. His first assignment was that of making a reconnaissance survey of two large areas in northwestern Wisconsin, a job he completed in a very credible manner.

In 1912 Professor Musbach was placed in charge of the research work on soil management on the northern Wisconsin substations in which he was engaged until his death. In 1937 the people of that region celebrated the completion of 25 years which he had devoted to the study of their soil problems and erected a plaque expressing their appreciation of his labors in their behalf.

Professor Musbach attended the second meeting of the American Society of Agronomy at Omaha and was a member and regular attendant on essentially all meetings thereafter. His more important contributions have been based on studies of the silt loam soils derived from old glacial drifts in a region of crystalline rocks in the north central and most intensive dairy region of the state. These studies included work on methods of maintaining organic matter, of their fertilizer needs, and of the physical and chemical conditions in relation to the growth of legumes, especially of alfalfa. For a number of years he has given special attention to the soil and fertilizer problems of the two most important special crops of Wisconsin, namely canning peas and potatoes.

His papers in the JOURNAL deal with the relation of weather as a factor in crop production and on the effect of fertilizers on the quality and chemical composition of canning peas. His last paper, in cooperation with Professor J. C. Walker, is a study of the relation of root rot infestation of peas to fertilizer application and will appear soon in the JOURNAL OF AGRICULTURAL RESEARCH.

In addition to papers on research projects Professor Musbach wrote a number of bulletins of an extension character on various soil problems of the region.

Professor Musbach was a man of exceptionally fine personality, of great physical and intellectual energy, and was a recognized leader in the educational and civic groups of the region of his life's work. Announcement has just been made that in his will he has provided that half of his estate will be given to the College of Agriculture for the establishment of fellowships providing for further study of the problems of soil management. His wife, an invalid for many years, died in January of this year and their only child, William F., is now engaged in work with the Department of Agricultural Economics following completion of his graduate work at the University of Wisconsin.—A. R. WHITSON.

CHARLES FREDRICK SHAW

CHARLES FREDRICK SHAW, Professor of Soil Technology at the University of California, and Soil Technologist in the Agricultural Experiment Station, passed away in Berkeley, California, on September 12 after a brief illness. Born in West Henrietta, New York, May 2, 1881, after a brief period of preparatory schooling he entered Cornell University from which he was graduated in 1906. Shortly after graduation he was appointed Scientific Assistant in the Division of Soil Survey, Bureau of Soils of the U. S. Dept. of Agriculture. After a period of service in soil survey work in Louisiana and Texas he accepted an appointment as Instructor in Agronomy at the State College of Pennsylvania in 1907 where he became Assistant Professor of Agronomy in 1909. During his period of service at Pennsylvania State College he participated in soil surveys in cooperation with the Bureau of Soils in various areas in that state.

In 1913, under Dean and Director Thomas F. Hunt, who gathered about him a group of very able men, Professor Shaw was called to the University of California to a position which he occupied and faithfully filled, except for brief periods of leave, until his death. In addition to a heavy burden of teaching, he found time for activity in research and publication of numerous technical papers dealing with soil surveying and soil classification, and under his able direction a program of soil surveys in California in cooperation with the Bureau of Soils, later Bureau of Chemistry and Soils and Bureau of Plant Industry, was built up. During this period a total of more than 60 detailed and reconnaissance soil surveys were completed, in addition to which he conducted a number of independent soil surveys and studies in the state for the California Department of Public Works and other official and local organizations.

He was widely traveled, accompanied by Mrs. Helen Hosterman Shaw whom he married in 1909. He visited and studied soil and agricultural conditions in Australia, New Zealand, Hawaii, and many other regions and countries. In 1930 he was Visiting Professor at the University of Nanking where he conducted extensive field studies in China and laid the basis for systematic soil surveys later undertaken. Several summer periods were spent in Mexico in an advisory capacity to the National Commissioner of Irrigation in teaching and training a corps of men in soil surveying. He served at various times as a member of various advisory committees and in field investigations for the U. S. Reclamation Service and other federal and state organizations.

He was a member of the International Society of Soil Science and official delegate of the University of California to International Soil Congress sessions held in Washington, Russia, and England in the proceedings of which he took active part, and had been asked to succeed the late Dr. C. F. Marbut as Chairman of Commission V, Subcommission for North America. He was a Fellow of the

American Society of Agronomy, of the American Geographical Society, and of the American Association for the Advancement of Science, and a member of the Soil Science Society of America and a past President of the American Soil Survey Association which preceded it. He was also a member of the American Society of Agricultural Engineers, Western Society of Soil Science, California Academy of Sciences, and of other scientific, fraternal, and social organizations, including Alpha Zeta and Sigma Xi. Funeral services attended by a large circle of associates and friends were conducted with Masonic rites.

In his office as teacher his advice and counsel was constantly sought and freely given, for it was his province not only to teach but to inspire. Good teacher—good scientist—good citizen—good friend.—MACY H. LAPHAM.

FRED WILLIAM TINNEY

FRED WILLIAM TINNEY was born at Saco, Montana, October 30, 1907. After graduation from the local high school, he entered the State Teachers' College, Oshkosh, Wisconsin, where he received the degree of B.Ed. in 1929. He spent two years at the University of Oklahoma as assistant in botany, taking an M.S. degree in 1931. He then came to the University of Wisconsin as research assistant, which position he held until his appointment, in February, 1936, as assistant agronomist in the Bureau of Plant Industry, U. S. Dept. of Agriculture. The degree of Ph.D. was received in 1933.

His research included a thorough-going study of heteropycnosis in two species of *Sphaerocarpos*. After this came an investigation of the cytology of an ornamental grass, *Agrostis nebulosa*. This led naturally to the study of the genetics and cytology of pasture grasses. After Dr. Tinney's appointment in the Bureau of Plant Industry, work in this field was carried on at Madison in cooperation with the Department of Agronomy of the University of Wisconsin. A paper embodying his extensive studies of blue grass (*Poa pratensis*) is in press. This grass has been the source of much confusion because of the multitude of races included within the species, and of the variety of chromosomal conditions which these races manifest. Tinney's observations of the peculiar methods of embryo-sac and embryo-development characterizing the species go far toward explaining the peculiar genetic behavior of its varied forms. It promises, too, to supply a basis for the selection and breeding of improved strains of this and other grasses—a relatively new field of endeavor in America.

Deeply devoted to fundamental research in accordance with his training and inclinations, Doctor Tinney in his later work developed a keen insight into the applied aspects of his studies. Quiet and unassuming, he was highly respected by his fellow workers and many friends, who recognized in him the qualities of substantial leadership among the younger group of American scientists.

He married Madeline Morrissey on June 12, 1939. Both Doctor and Mrs. Tinney attended the International Congress of Genetics at Edinburgh and were passengers on the ill-fated *Athenia* sunk off the coast of Scotland, September 3, 1939. They were among those listed as missing after the disaster.—C. E. ALLEN, R. A. BRINK, and L. F. GRABER of the University of Wisconsin, and O. S. AAMODT, of the Bureau of Plant Industry.

NOMINATING COMMITTEE

THE Nominating Committee consisting of R. J. Garber, *chairman*, and F. D. Keim, W. A. Albrecht, H. C. Rather, and A. M. O'Neal, made the following nominations: Dr. Richard Bradfield of Cornell Universiry as representative on the Union of Biological Sciences; Dr. R. M. Salter of the Ohio Agricultural Experiment Station and Dr. S. T. Dexter of Michigan State College as representatives of the Society on the Council of the American Association for the Advancement of Science; and for Vice-President of the American Society of Agronomy, Dr. L. E. Kirk of Ottawa, Canada.

Upon motion the Secretary was instructed to cast one vote for these nominees and they were declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary*.

AGRONOMIC AFFAIRS

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1940

President, F. J. ALWAY, University of Minnesota.
Vice-President, L. E. KIRK, Dominion Agr. Exp. Station, Ottawa, Canada.
Chairman, Crops Section, S. C. Salmon, U. S. Dept. of Agriculture.
Chairman, Soils Section, W. H. PIERRE, Iowa State College.
Editor, J. D. LUCKETT, New York State Agr. Exp. Station.
Secretary-Treasurer, G. G. POHLMAN, West Virginia Agr. Exp. Station.
Members of the Executive Committee, R. J. GARBER, U. S. Dept. of Agriculture, and EMIL TRUOG, University of Wisconsin.

OFFICERS OF THE CROPS SECTION FOR 1940

A NOMINATING Committee appointed by Professor F. D. Keim, *Chairman* of the Crops Section, at the business meeting of the Section held in New Orleans November 22 was composed of R. D. Lewis, *Chairman*, and R. G. Wiggans and M. T. Jenkins. The committee presented the following slate of officers for the Section for 1940 which was unanimously approved: For *Chairman*, S. C. Salmon of the U. S. Dept. of Agriculture, and as members of the Executive Committee of the Section, P. C. Mangelsdorf of the Texas Agr. Exp. Station and C. J. Willard of Ohio State University.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1940

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Past President, WM. A. ALBRECHT, University of Missouri.
Secretary, C. E. KELLOGG, U. S. Dept. of Agriculture.
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Editor, J. D. LUCKETT, New York State Agr. Exp. Station.

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Section II

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Secretary, H. H. KRUSEKOPF, University of Missouri.

Section VI

Chairman, H. E. MIDDLETON, U. S. Dept. of Agriculture.
Past Chairman, W. L. POWERS, Oregon State College.
Secretary, W. W. WEIR, University of California.

MEMORIAL SERVICE FOR DOCTOR LIPMAN

A memorial service for the late Dr. J. G. Lipman was held at Temple Emanu-El, Fifth Avenue and 65th Street, New York City, on Sunday afternoon, November 26, 1939, under the auspices of a number of learned societies and organizations, including the American Society of Agronomy. Among the speakers at the service were Dr. Henry G. Knight of the U. S. Dept. of Agriculture, Dr. Gabriel Davidson of the Jewish Agricultural Society, Professor O. S. Morgan of Columbia University, Dr. Carl B. Woodward of Rutgers University, Dr. Harold B. Allen of the National Farm School, and Dr. Arthur D. Goldhaft of the Baron de Hirsch Agricultural School.

JOHN JACOB PIEPER

DR. John Jacob Pieper died November 26 at Pana, Illinois, as a result of a heart attack while on his way home from the New Orleans meeting of the American Society of Agronomy. Doctor Pieper was Professor of Crop Production in the College of Agriculture, and Chief in Crop Production in the Agricultural Experiment Station, University of Illinois, with which he has been connected for 22 years.

Doctor Pieper graduated from the University of Illinois in 1916; received the M.S. degree from the same institution in 1917; and ob-

tained the Ph.D degree at the University of Wisconsin in 1927. He was a member of the American Society of Agronomy, and the Sigma Xi, Alpha Zeta, Phi Sigma, Gamma Sigma Delta, and Theta Chi fraternities.

In addition to his striking success as a teacher, he made noteworthy contributions in the field of research. During the later years he gave special attention to the subjects of pasture improvement and weed control. The long list of bulletins, circulars, and journal articles, of which he is author or co-author, testify to his productiveness in the field of research.

NEWS ITEMS

ON SEPTEMBER 1, D. D. Mason, Assistant Agronomist, Virginia Agricultural Experiment Station, resigned from his duties as Soil Surveyor to accept a fellowship in the Agronomy Department at Ohio State University, where he hopes to take the Ph.D. degree in Soil Fertility. Mr. Mason received his M.S. degree in Agronomy from Virginia Polytechnic Institute in June 1938. Mr. Ashton Sinclair, a 1938 graduate of V. P. I., was added to the Experiment Station staff to fill the vacancy caused by Mr. Mason's resignation.

DR. WERNER HUSMANN, a graduate of the University of Berlin, and formerly connected with the German Nitrogen Syndicate, was employed as Assistant Professor of Agronomy at Virginia Polytechnic Institute, effective October 5.

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